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ABSTRACT

This teacher's guide is part of a program of activities that help secondary-level students develop the complex thinking skills needed to succeed in science. This program can be used with current curriculum materials. It is designed to help students integrate ideas and develop concepts that demonstrate higher level thinking. A rich environment of experience and thinking opportunity supports and guides students to an optimal level of performance. The 30 activities in this guide are presented in the following format: An introduction sets the objectives of the activity and points out the main idea on which to concentrate. An apparatus summary provides a checklist of the supplies that will be required. A procedure summary outlines the steps and ideas of the lesson. This summary is intended as an aid during the lesson. Following the procedures are the student materials. The activities encompass the topics of variables, proportionality, compensation, probability, classification, formal models, compound variables, and equilibrium. (PR)

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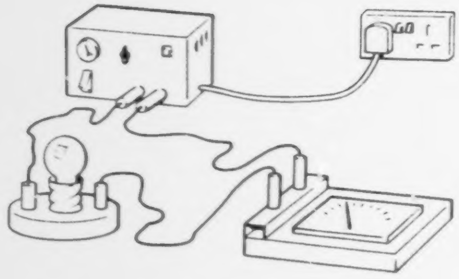
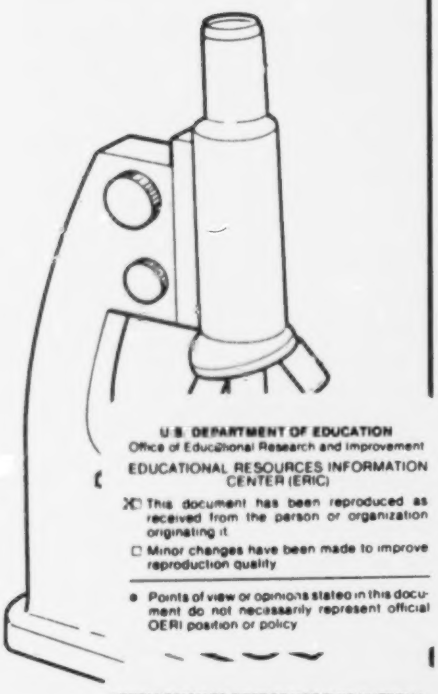
Thinking Science

Teacher's Guide





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Thinking Science:
Classroom Activities in Secondary Science

TEACHER'S GUIDE

Philip Adey, Micheal Shayer, and Carolyn Yates
King's College London, Centre for Educational Studies

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Preface

Research for Better Schools (RBS) is pleased to make **Thinking Science** available to American educators. This curriculum of 30 "enrichment" activities is based on the Cognitive Acceleration through Science Education (CASE) project, conducted in Great Britain. **Thinking Science** helps secondary level students develop the thinking skills needed to succeed in science courses and careers.

RBS is committed to the central importance of higher order thinking skills in improving both educational quality and equality of opportunity. We selected **Thinking Science** for distribution because of its usefulness and effectiveness as evidenced in extensive classrooms tryouts.

This version of **Thinking Science** has not been "Americanized" in all language aspects, but some changes have been made for the purpose of communication and compatibility with the American classroom. As examples of language differences you will see, the activities "Tea Tasting" and "Up Hill and Down Dale" might seem more American as "Coffee Tasting" and "Peaks and Valleys." Other language differences include:

British	American
cm^3	ml
metres	meters
tick	check
petrol	gasoline
torch	flashlight
lollies	lollypops
colour	color
behaviour	behavior
formalise	formalize
summarise	summarize

We hope that this international flavor adds to your experience **with Thinking Science.**

The **Thinking Science** materials consist of this Teacher's Guide and accompanying Student Manuals, which are packaged in sets of 10. The Teacher's Guide contains instructions to the teacher and explains the content of each of the 30 activities. This is preceded by an introduction to **Thinking Science** and followed by an appendix, which provides details on the apparatus needed for each activity. The Student Manual includes the information and worksheets each student needs for the 30 activities.

Keith M. Kershner
Director, RBS Publications

Introduction

Teachers have little time to read teacher's guides; therefore, we offer you a two-part introduction. The first part explains, albeit briefly, the psychological foundation for **Thinking Science.** It also discusses classroom tryouts of the materials. The second part of the introduction gives practical directions for the teacher who wants to move right into the activities. It is not essential to read the first section of the introduction before using **Thinking Science** activities. You will, however, use the activities far more effectively if you understand why they are the way they are.

The Thinking Behind Thinking Science

The psychological model can be stated thus: Sometime between the ages of 12 and 18, young people's thinking goes through a qualitative change, something like shifting up a gear. Using Piaget's labels (without implying a hook, line, and sinker adherence to Piagetian psychology), whereas in the early teens the student is still using **concrete operational thinking;** later adolescents are more likely to be able to use **formal operational** thinking. To relate **Thinking Science** to this qualitative development of thinking, we must first say a little more about the nature of concrete and formal operations, then recall some evidence that we have about the proportion of students at different ages who use each operational type, and finally indicate the basis for our optimism that these proportions are not immutable.

Concrete operational thinking is sometimes mistakenly linked to concrete "hands-on" experiences. Concrete operations are thought processes which a child performs on his or her perceptions. The perceptions may arise from some practical activity, but may also arise from something read, or something someone says. Important characteristics of concrete operations are that they can cope with only a limited number of variables and that they allow the child to **describe** situations, but not to **explain** them. By contrast, formal operations can handle multi-variable problems, and allow people to explain events. In describing an ecosystem, for instance, a child using concrete operations can describe simple food chains, and see that the population of one species (for instance, ladybirds) is related to the population of another (aphids). Children can understand this whether or not they performed some practical activity. But the ability to comprehend the dynamic equilibrium of multiple variables in the ecosystem, and appreciate in principle how a small shift in one factor may have far reaching effects, or alternatively may be compensated by a shift in the equilibrium position, requires a higher level of thinking.

During adolescence, many people develop the ability to think in formal operational terms. The mechanism by which this development occurs is by no means certain. Piaget described it in terms of interaction between the individual and the environment, with new stimuli being assimilated into existing structures, or the cognitive structure accommodating to new stimuli when they could not be simply assimilated. Whether or not one accepts such a theory, the development of cognition is surely influenced by a person's genetic make-up, by nutritional factors, and by physical and social environmental factors from the moment of conception onwards. Such environmental factors must include the influence of schools and of teaching.

While it would be foolhardy to try to quantify the relative effect of these different factors on an individual's cognitive development, it seems reasonable to assume that the influence of secondary school teaching is significant. The optimism of the **Thinking Science** approach lies in that assumption.

Thinking Science is all about encouraging the development of thinking from concrete to formal operations. Why this should be of special concern to science teachers becomes clear if one looks at a list of some of the types of reasoning (Piaget called them schemata) that are characteristic of formal operations:

- control of variables and exclusion of irrelevant variables
- ratio and proportionality
- compensation and equilibrium
- probability and correlation
- use of abstract models to explain and predict.

We will not describe these schemata in detail here, since **Thinking Science** activities provide many examples of them in contexts familiar to science teachers. However, it is certain that no student can really be competent in any science subject without using these formal operations schemata. Further, America's national goal related to science cannot be achieved without this higher level of thinking in science courses.[1]

Link this now to what we know about the development of formal operational thinking in the school population. For example, currently about 28 percent of British 14-year-olds demonstrate some ability to think formally.[2] If the most effective learning in secondary science requires formal operational thinking, then the proportion of adolescents currently able to learn science effectively is disturbingly low.

On what grounds do we believe that it is possible to raise the levels of thinking of ordinary students in ordinary schools? Before attempting to answer that, it is necessary to say something about transfer. Suppose, after assiduous work by teacher and student on the variables that affect the rate of a swing on a pendulum, a student shows that she is able to design experiments in which the variables of mass, amplitude, and length are properly controlled. We would say that the student had learned successfully about control of variables in one specific context — a straightforward learning experience. If the student then demonstrates improved performance in designing a controlled experiment to investigate the effect of a fertilizer on plant growth, then we would say that some transfer has taken place. The control-of variables schema has been developed beyond the confines of a particular context. This is **near-transfer,** or specific transfer.

Far-transfer, or general transfer, would happen if the same student, following her learning about controlling pendulum variables, also demonstrates an improved ability to perform proportionality problems. This is a completely different type of reasoning and, if such far-transfer were to happen, it would strongly suggest that the student's ability to think has been generally improved by the pendulum learning experience. In a sense, general transfer is an objective (usually implicit) of all science curricula, indeed of all schooling. We do hope and believe that children's general thinking ability

improves as a result of their going to school. And yet, a review of studies of cognitive acceleration shows that specific learning is very common, that near-transfer can be achieved by carefully designed programs, but that far transfer is elusive.[3] Those who have succeeded in raising students' levels of thinking across a range of reasoning patterns through activities that address only a limited sample of schemata seem to have done so by a back door, roundabout approach. For instance, in Australia, Dorothy Rosenthal got her students to concentrate on the dimensions of some practical physics problems. Without ever teaching a control-of-variables strategy, her students showed improved performance both in controlling variables, and in the completely different schema of proof strategy. Learning from such experiences of others, the authors developed, tried, and tested a technique of teaching science which could promote general thinking. The **Thinking Science** activities crystallize, insofar as a written guide can, examples of that teaching technique.

Each activity concentrates on one schema of formal operations, but none attempts directly to teach strategies for solving problems using those schemata. We believe that such a direct approach could lead, at best, to no more than specific transfer of the application of a schema mastered in one context to another context. Most

Thinking Science activities start with some practical experience requiring only concrete operations. This enables students to become familiar with the terminology and context of the problem within the comfort of well-exercised thinking levels. The higher level thinking that follows is difficult enough without being further fogged by the need to accrue meaning to a set of new words at the same time. Typically, the concrete introduction is followed by a practical exercise, but one which cannot be solved using concrete operations. The student is familiar with the apparatus, knows what the words mean, but needs to accommodate his or her thinking to a higher level in order to cope with the new problem. We say more, at a practical level, about this sort of "cognitive conflict" in the following section, "How to Use Thinking Science."

The **Thinking Science** activities were tried out over a two-year period by the authors and by many others. We taught them in "laboratory" schools, schools where classes using the materials made significant gains in cognitive development compared with control groups. Even more encouraging (since less "special") were the results obtained in the main experimental schools, eight schools which used the activities regularly over a two-year period. The experimental group showed a significantly greater gain on measures of formal operational thinking, compared with a matched control group immediately after the intervention program. Up to three years later, experimental students were still showing better performance in national (U.K.) tests of science, mathematics, and also English. Full details of the results are published elsewhere.[4] Even before these results were known, the overwhelming opinion of teachers who used the activities was that they were stimulating, novel, and valuable additions to existing curricula.

How to Use Thinking Science

This section presents practical information on using **Thinking Science** in your school. It is organized in answer to basic questions teachers have about the program.

What is the purpose?

Thinking Science is a program of activities that help secondary-level students develop the complex thinking skills needed to succeed in science.

Why use Thinking Science?

Thinking Science is a developmental program that you use with your current curriculum materials. It is designed to help students integrate ideas and develop concepts that demonstrate higher level thinking. Most students do not understand or internalize science when it is taught by "covering" the text using didactic instruction. When a teacher uses **Thinking Science,** a rich environment of experience and thinking opportunity supports and guides students to an optimal level of performance.

What's included in the materials?

The 30 activities in the Teacher's Guide are presented in the following format: An **introduction** sets the objectives of the activity, and points out the main idea on which to concentrate. An **apparatus summary** provides a checklist of the main things that will be required. A **procedure summary** outlines the steps and ideas of the lesson. This summary is intended as an aid during the lesson. The full **procedure details follow and should** be studied well before the lesson. The student materials for each activity are then presented; these pages are numbered both as they appear in the Teacher's Guide and the Student Manual for the teacher's convenience. Apparatus details are given in the appendix.

The student also has his or her own Student Manual. It is not a workbook; it is a guide to thinking and science experiences. When a student uses it and participates in class, he or she will manipulate equipment and materials, collect data and interpret them, become familiar with new terminology, take part in discussions, and make conclusions. Through direct instruction, experimentation, and inquiry, the student will develop generalized concepts. The student materials include **worksheets** (w/s) for recording observations and data for each activity. Most activities also have **workcards** (w/c) which provide instructions, information, and problems. Some have **example cards** (e/c) that contain illustrations of concepts for discussion. The teacher may find it useful to make overhead projector transparencies of the example cards for use in class. All pages in the Student Manual are perforated and printed on one side only, so that they can be shared in student groups or passed in for review, if desired.

When do you use Thinking Science?

This program is not a complete course. It is intended to "enrich" the curriculum already in place. If a school has adopted a philosophy of handson, experiential, inquiry-based instruction and has set high expectations for student achievement, this program fits right in. It is aligned with the objectives and concepts presented in 7th grade through high school. Students vary in abilities and readiness to acquire new cognitive skills; but at some point in middle adolescence, there occurs a cluster of spurts in optimal performance.[5] This is the most opportune time to experience a developmental program like **Thinking Science.**

How are activities selected and scheduled?

There are 30 activities in **Thinking Science.** Each is designed to last about an hour, although the first time you teach them may take longer. Two class periods offer a comfortable amount of time for a complete activity. In the trials, schools used the activities at the rate of about one every two weeks over a two-year period. This schedule was determined by a combination of what the authors believed to be a necessary minimum to have a substantial effect, and what schools could practically incorporate into their existing curricula. Many teachers will want to select activities from **Thinking Science** for particular purposes. This is easy to do since many activities are self-contained, or at most, require a mini-set of two or three activities that make sense together. The activities are not labelled "biology," "chemistry," or ''physics,'' although you could identify them as such if you wish. In trial schools they were used in both integrated science situations and where separate sciences were taught.

Is order important?

Although each lesson is considered self-contained, grouping the lessons according to concept will enhance the connections that students make. Used as a complete set, **Thinking Science** will lead to improved general reasoning processes and complex thinking among students.

For instance, some of the work on **variables and relationships** (a selection from the first five activities) is assumed by almost all of the activities that follow. At least some of the **proportionality activities** (6 to 9) should also be done early on. On the other hand, the **formal models** (23-25), **compound variables** (26, 27, 30), and **equilibrium** (28, 29) activities can be taken in any order.

What is the best teaching method?

To a greater or lesser extent, every science curriculum or textbook considers the importance of content, processes, social and technological connections, and other dimensions of science relevant to school teaching and learning. Each implies a certain teaching method, although perhaps not outrightly so. In the case of **Thinking Science,** the teaching method is strongly emphasized.

Teachers using Thinking Science effectively will shift away from the "sage on the stage," linear teaching model (teacher-based, hierarchical, giver of knowledge) to "a guide on the side," geodesic model (student interactive, higher order thinking). This is what makes Thinking Science a valuable tool for teachers to use.

Simply proceeding through the 30 activities as practical exercises in which students do experiments, make observations, record results, and struggle by themselves to reach conclusions is unlikely to have any useful effect. The essential feature of **Thinking Science** is the concentration on the student's thinking. This happens in a number of ways.

- **Class discussions, pre, during, and post-experiment.** In these activities, the teacher is more than a resource manager, more than a "facilitator of learning." The teacher is a director of the activities and of the discussions that are critical to the development of thinking.

  Most activities start with a straightforward concrete practical experience. The purpose is for students to become familiar with the terminology to be used, and with the apparatus and the practical context. New words are highlighted in the Teacher's Guide and should be practiced by the students. Teachers should shape word use so that the full meaning grows in the student's mind. The development of a shared language between teacher and student is critical to the success of the development of thinking in the lesson. Teachers should use monitoring, feedback, clarifying, and consensus techniques.

  There are often points during the activity when it is necessary to call the whole class together, summarize what has been done, consolidate observations, and start to speculate on explanations, or the best way to proceed. Closure should include summarizing the meanings of newly acquired words, checking on student understanding, rethinking the process used during the lesson, and linking the work to other experiences in the school curriculum and in everyday life.

- **Cognitive conflict - discrepancies.** In a number of activities, students will make observations that will come as something of a surprise to them, since the observations do not fit their expectations. They may have been set up through an initial practical activity, or they may be part of the student's previous learning — formal or informal. This sort of surprise — sometimes called cognitive conflict — is an important element in cognitive development. When a child perceives evidence that does not fit in with a preconception, she must restructure her way of thinking in order to accommodate the new evidence.

  Development may fail to occur after cognitive conflict either because the child already has well developed thinking skills that can easily assimilate the new evidence or, far more common, because she does not yet have sufficiently developed reasoning to see the situation as surprising. Very young children and older slow learners are often able to simultaneously maintain two ideas or observations which to an adult seem inconsistent. This is because the ideas are serially processed one after the other and not considered together. Also, it is important to make sure terminology is consistent and accurate. Many teachers fail to notice although the thinking process is engaged, students articulate the wrong terms. This is an important time for active listening.

- **Metacognition.** Metacognition means thinking about one's own thinking. The **Thinking Science** teacher will often ask students, "How did you solve that?" "Please explain to the others in your group why you think that." An important part of developing thinking skills is for students to become conscious of and articulate the sort of thinking they are employing to solve different problems. Thinking back and reflecting aloud helps to develop this consciousness.

- **Bridging.** Bridging means simply linking ideas developed in **Thinking Science** activities to parallel experiences in the rest of the science curriculum and in everyday experience. Without this sort of mental bridging, there is a danger that the Thinking Science activities will remain "peculiar" or "special," with their effects linked to certain types of activity and not generalized either in science or beyond it.

Conclusion

Thinking Science activities are designed to provide students with opportunities to develop and practice higher order thinking skills. After you have used them for a while, you will see how well they fit into your regular science curriculum. It is possible that without using the particular activities given here, you will absorb the **Thinking Science methodology** into your teaching.

A final note of encouragement: Taught properly, **Thinking Science** is hard work for both teacher and students. The amount of mental effort required sets it apart from normal practical activity-based science curriculum materials. Nevertheless, you will find the effort worthwhile.

Note on Assessment

Conventional tests concentrate on knowledge of content. Better designed ones probe comprehension and the ability to apply concepts to novel situations. Many newer tests attempt to assess students' use of process skills. In trying to chart the development of student thinking, we have used some of these types of tests, but the most direct measurement of the development of formal operational thinking is through Piagetian Reasoning Tasks. These tasks were developed at Chelsea College and originally published by the British National Foundation for Educational Research. They are now available from the authors through Research for Better Schools, 444 N. 3rd Street, Philadelphia, PA 19123. For assessment information, the reader is also referred to the work of the Northwest Regional Educational Laboratory in Portland, Oregon[6].

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The Activities

Activity 1: What varies?

Variables

Introduction

The terms 'variable' and 'value' (as it applies to variables) and 'relationship' are introduced, together with the possible relationships between two variables. These are described in terms such as:

'when one goes up, the other goes up'
'when one goes up, the other goes down'
'they are not related'.

Pupils work through a set of illustrated examples to get used to using the words and concepts of 'variables', 'value' and 'relationship'.

Apparatus summary

For demonstration

- Collection of books, varying in colour, size, etc.
- Set of six coloured squares and triangles
- Four beakers: two large blue (no. 1 empty, no. 2 with 100 g mass), two small red (nos. 3, 4) weighted so that 3 weighs the same as 1, and 4 the same as 2
- Simple balance

Per pupil

- Worksheet
- Workcard

Procedure summary

1 Discussion of possible relationships: number of holly berries and coldness of winter; colour of cars and number of accidents, etc. What are the **variables**? Number of berries, coldness of winter; colour of car, number of accidents.

2 Collection of books: what are the variables? what are the **values**?

3 Three blue triangles and three red squares: What **relationship** is there between colour and shape? Given this relationship, predict colour from shape, shape from colour.

4 Rearrange shapes to get new relationship: colour related to size.

5 Loaded beakers: relationship between colour and size. *No relationship* between weight and colour or size.

6 Practice with relationship Workcard.

Procedure details

1 One of the things we are interested in in science is relations, or connections, between different things:

> 'If there are a lot of berries on the holly, it will be a cold winter.'
>
> 'Black cars have more accidents than yellow cars.'

We can study how true these statements are by seeing whether there is a relationship between number of berries and coldness of winter. (You could discuss 'relations' briefly in terms of family relations – some sort of connection.) But first we must be clear what it is we are looking for. What are the things that *vary*, or differ? We use the word variable to describe things that can vary.

In this case

variables (things that vary):	*number of berries*	*coldness of winter*
values:	lots	cold
	few	mild
variables (things that vary):	*number of accidents*	*colour of car*
values:	lots	black
	few	yellow

2 Spread a number of books about on a table where all can see. How do these books differ from one another?

For example, 'size' – yes, they vary in size, size is one variable. What other variables are there? . . . and so on for colour, cover type, or whatever else comes up, using the chalkboard to develop a list under the heading variable.

Now, what *values* do each of these variables have? The values of colour are red, blue, green, etc. For each variable in the list, get pupils to suggest values – which may just be 'big', 'medium', 'small' (try to avoid getting into definition problems at this stage).

3 Put the books away, and lay out (or stick up) where all can see:
three blue triangles and
three red squares.

Pupils should be able to say what are the variables (size, shape and colour) and values (small/medium/large; square/triangle; red/blue). These go in the first table of the Worksheet.

Now, is there any *relationship* between them? Do shape, colour and size 'go together' in any way? Elicit something like 'triangles are all red. Colour and shape are related, there is a connection between them. If you were to say the next shape you bring out will be blue, pupils can tell that the shape must be square. If the next shape you show were to be a triangle, pupils can predict that it would be red. A relationship between variables allows you to say what will happen next.

4 Now lay out the large blue square, large blue triangle, medium red square, and medium red triangle. Same variables – but what is the relationship now? Elicit colour related to size. (Part 2 on the Worksheet.)

5 Produce the four prepared beakers.
Variables (that they can see)? colour and size.
Values? red/blue, large/small.
Relationship? colour goes with size.
Now feel the weight of two of the beakers in your hand, and push forward the balance, as a clue to 'What other variables may there be?' If necessary, get a pupil to feel the weight of the small lighter and big heavier beaker. As necessary, help pupils to complete the tables (Part 3 on the Worksheet), except for the weight column.

Beaker number	Colour	Size	Weight
1	blue	large	(150 g)*
2	blue	large	(250 g)
3	red	small	(150 g)
4	red	small	(250 g)

Then as a demonstration, possibly with pupils' help, weigh the beakers and complete the table. What is the relationship? Surprisingly, there is none. There is a heavy blue and heavy red. So here is a case where there is *no relationship* between two variables. In order to understand the notion of relationship, they must encounter examples of no relationship.

(* Of course, your weights may be different, but this is the pattern.)

6 Now refer to the 'relationship' Workcards. Pupils can work in groups of two or three. For each picture they should determine:

- What are the variables (what are the things that vary)?
- What are the values of each variable?
- Whether there is a relationship between the variables? And if so, what sort of relationship? Relationships can be described as 'they go up together', or 'one goes up while the other goes down'.

Some possible answers are given below, although there are plenty of correct alternatives.

Possible answers to the relationship Workcard

Page	Variables	Values	Relationship
1 Boiling	burner flame	high medium low	
	bubbles	many some few	the higher the flame, the more bubbles
1 Candles	length of candle	long medium short	
	height of holder	tall medium short	the taller the candle, the shorter the holder
2 Eggs	egg size	large medium small	
	spoon size	large medium small	no relationship
2 Sausages	number of sausages	1 3 5	
	size of sausages	large medium small	as one goes up the other goes down
2 Shapes	size of triangles	large medium small	
	size of squares	large medium small	as one goes up the other goes down

Your name: ....

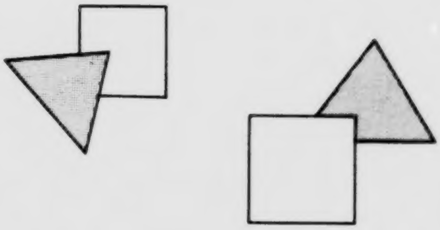
THINKING SCIENCE
ACTIVITY 1
WORKSHEET

Activity 1: Worksheet
What varies?

Variables

1 Paper shapes

Variable	Values
....	....
	....
	....
....	....
	....
	....
....	....
	....
	....



What is the relationship between two of the variables?

....

....

....

2 Paper shapes again

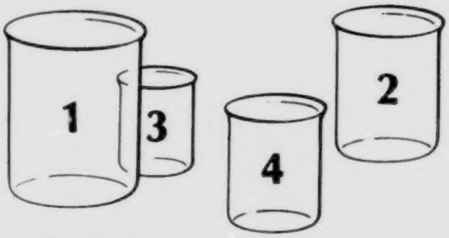
Now what relationship is there between two variables?

....

....

3 Beakers

Variable	Values
....	....
	....
	....
....	....
	....
	....
....	....
	....
	....



Beaker number	Colour	Size	Weight
1	....	....	....
2	....	....	....
3	....	....	....
4	....	....	....

▶

Your name: ....

4 *Relationships*

Page	Variables	Values	Relationship
1 Boiling	....	....	 ....
2 Candles	....	....	 ....
3 Eggs	....	....	 ....
4 Sausages	....	....	 ....
5 Shapes	....	....	 ....

Activity 1: Workcard
What varies?

Variables

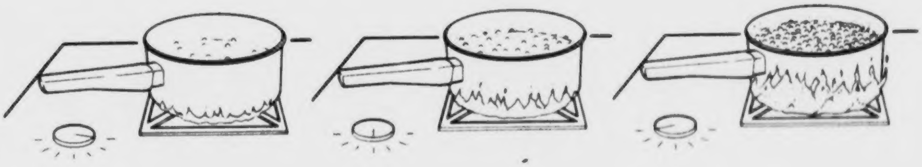
Variables, values, relationships

In each of the boxes on the following sheets there are three pictures.

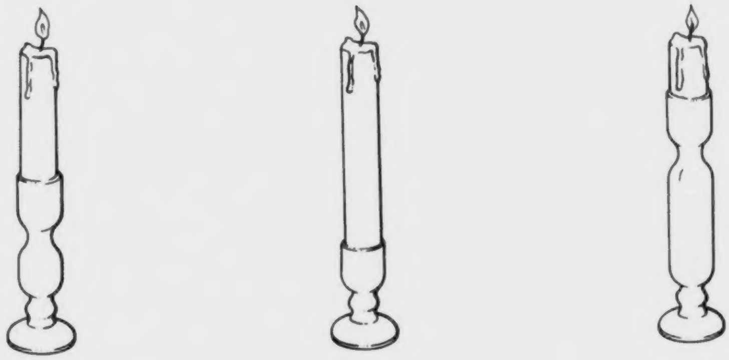
Some things vary from picture to picture, and some stay the same.

On your Worksheet, write what are the **variables** in each picture, what are their **values**, and whether there is any **relationship** between the variables.

Boiling



Candles



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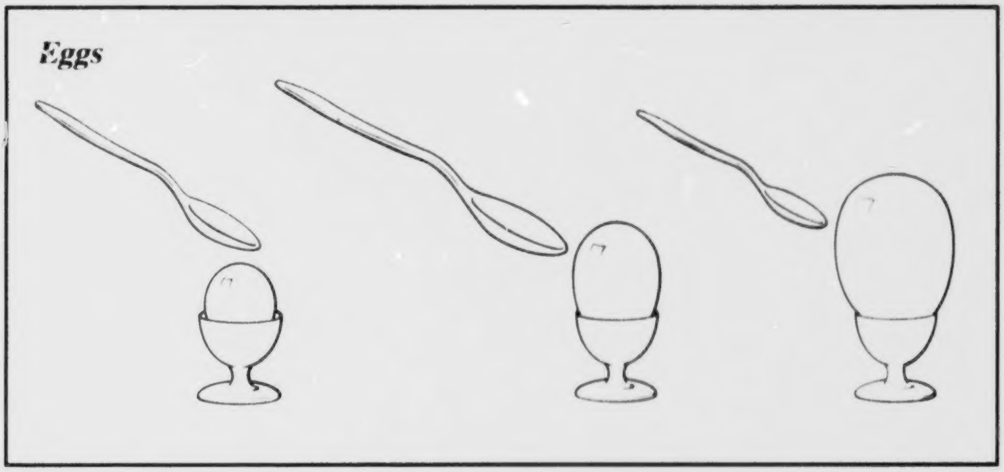
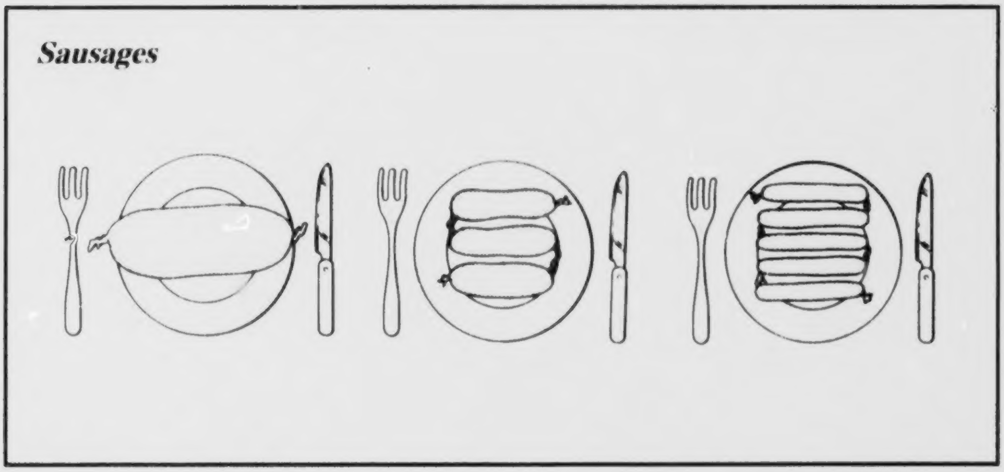
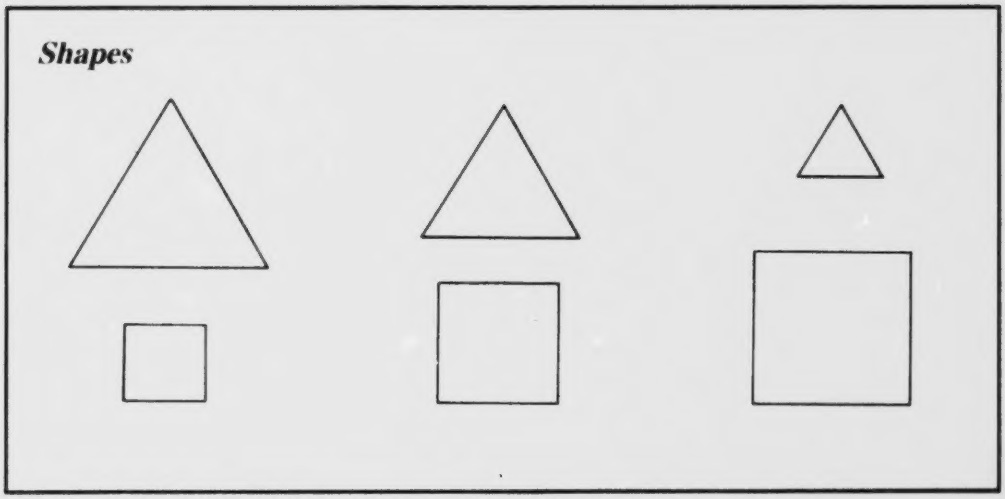
Eggs



Sausages



Shapes



Activity 2: Two variables

Introduction

This is a 'circus' of small experiments each of which involves two variables. The purposes are:

- to introduce the terms 'input' and 'outcome' variables (which we suggest as alternatives to the more usual, but confusing terms 'independent' and 'dependent'), and
- to consolidate notions of variables and relationships.

Apparatus summary

Note Advance preparation needed for experiment 3.

Eight sets of apparatus (two for each experiment) are arranged around the room with their Workcards.

Experiment 1:	Pulley, force measurer, weights. Workcard A
Experiment 2:	Circular containers of various diameters. Workcard B
Experiment 3:	Four leaves with Vaseline on: top surface, bottom surface, both surfaces, and neither; Workcard C
Experiment 4:	Workcard D

Per pupil

- Worksheet
- Workcard A, B, C, D
- Example Card

Each experment should take about ten minutes.

Procedure summary

1 Recap relationships between variables. This time they are going to change an 'input' variable and see what happens to an 'outcome' variable.

2 Four experiments as circus.

(A) Pulley: increasing the value of the input variable increase the outcome variable.

(B) Liquid heights: encourage search for pattern that as diameter goes up height goes down.

(C) Leaves: pupils assume that water cannot be lost through Vaseline and deduce from which side a leaf normally loses most water.

(D) Height/weight: no relationship (either could be the input or outcome variable).

3 Discuss results. Relate to other examples from science activities.

Procedure details

1 Remind pupils of the last lesson on variables, and relationships between variables. Two new examples are on the Example Card. Choose some examples from their regular science lessons to illustrate the use of these terms.

In this lesson, they are going to investigate variables further, and do some experiments in which one variable is changed and they see what happens to another. The variable that the experimenter (pupil or teacher) changes is called the **input** variable. The input variable is the one we have some control over. For instance, if we add more weights, weight is an input variable because we can decide whether or not to make it vary.

The other variable, the one that changes as a result of what we do, is the **outcome** variable. If you add weights to a spring, then the extension of the spring would be the outcome variable.

2 Arrange the class in groups, point out the four experiments, and explain how they are to do each in turn, as a 'circus'. The emphasis is on the variables and the relationship between the variables in each activity, although some useful content may be learnt as a by-product.

(A) The *pulley* is straightforward: increasing the value of the input variable increases the value of the outcome variable.

(B) For *liquid heights*, you may have to suggest that they write their results in order of increasing diameter, to see the pattern that as diameter goes up, height goes down.

(C) *Leaves* is the most difficult. The input variable is 'side with Vaseline', and the outcome is 'dryness'. Pupils must use the idea that water cannot be lost through Vaseline and deduce from which side a leaf normally loses most water.

(D) The *height and weight of children* example illustrates *no* relationship. Also, either could be the input or outcome variable.

3 When all have finished the activities, discuss results of each experiment, involving as many individuals as possible in telling the class about their answers and about their thinking. Recall other science activities they have done and question the input and outcome variables involved.

Your name: ....

Activity 2: Worksheet
Two variables

Variables

1 Pulleys

Weight	Force needed to lift it
g	N

What are the variables?

....

Which is the *input* variable?

....

Which is the *outcome* variable

....

What is the relationship between the variables?

....

2 Height of liquid

Container number	Diameter	Depth of water
	cm	cm

What are the variables?

....

....

What is the relationship between the variables?

....

▶

Your name: ....

3 *Leaves*

Freshness	Surface which is covered
freshest	
next freshest	
nearly dry	
driest	

Which is the *input* variable?

....

Which is the *outcome* variable?

....

Do you think that water is lost mostly from:

the top surface ....
the bottom surface ....
both surfaces equally ....
neither surface? ....

Why do you think so?

....

....

4 *Height and weight*

Write down the names of the six children *in order of their height*, with the shortest first and the tallest last.

Write in their weights in the third column.

Name	Height (in order)	Weight
	cm	kg

What are the variables?

....
....
....
....

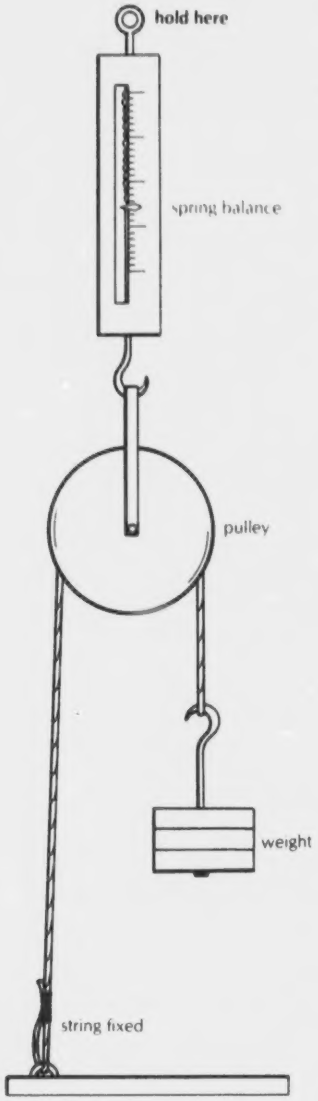
Is there a relationship between the variables?

....

Activity 2: Workcard A
Two variables

Variables

1 *Pulley experiment*


hold here
spring balance
pulley
weight
string fixed

Use the spring balance and pulley as shown to lift a weight.

The reading on the spring balance shows how much **force** you use to lift the weight.

Try three or four different weights. For each weight, find out what force you need to lift it.

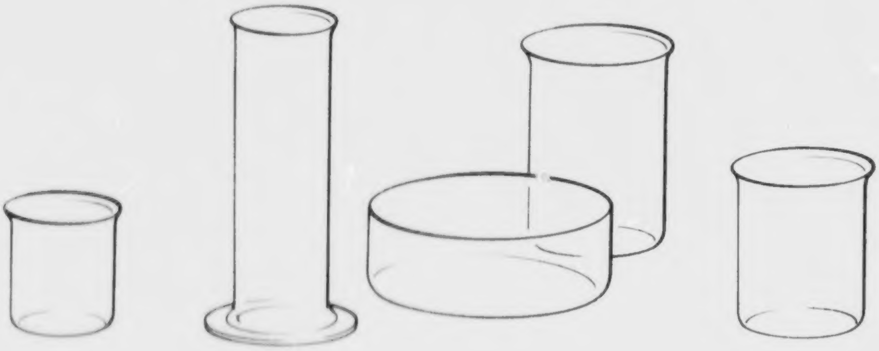
On your Worksheet (part 1), fill in the table and answer the questions.

Activity 2: Workcard B
Two variables

Variables

2 Height of liquid

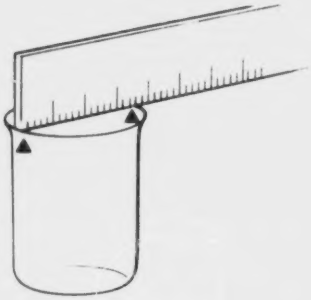
You have a number of containers. They have different heights and different widths. The smallest is a 100 cm^3 beaker.



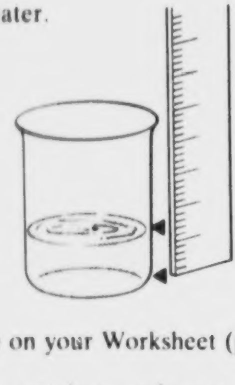
The smallest is a 100 cm^3 beaker.

Measure the *diameter* (the width across) of each container. Write the diameters in the table in your Worksheet (part 2).

Fill the 100 cm^3 beaker to the brim with water. Carefully pour it into one of the other containers.



Measure the *depth* of the water.



Write the result in the table on your Worksheet (part 2).

Pour the water into another container, and measure the depth of water in that.

Do the same for all of the containers you have, and put the results in your table. Answer the questions on your Worksheet (part 2). ■

Activity 2: Workcard C Two variables

Variables

3 *Leaves*

A fresh leaf contains water. When a leaf loses water, it dries up and becomes shrivelled.

The leaf may lose water from its top surface, or from its bottom surface, or from both. This experiment will help you find out which surface a leaf loses water from.

Two days ago, some Vaseline was spread on some of the leaf surfaces. If a surface has Vaseline on it, water cannot escape from that surface.

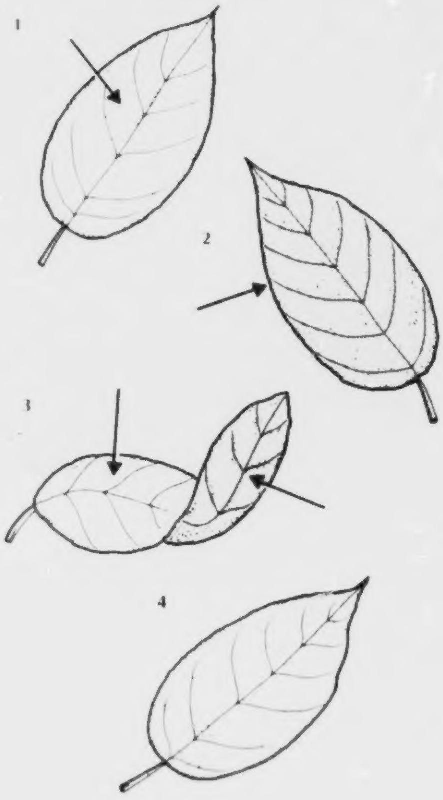
Look at the four leaves hanging up.

Leaf 1 had Vaseline spread on its top surface.

Leaf 2 had Vaseline spread on its bottom surface.

Leaf 3 had Vaseline spread on both of its surfaces.

Leaf 4 had no Vaseline spread on its surfaces.

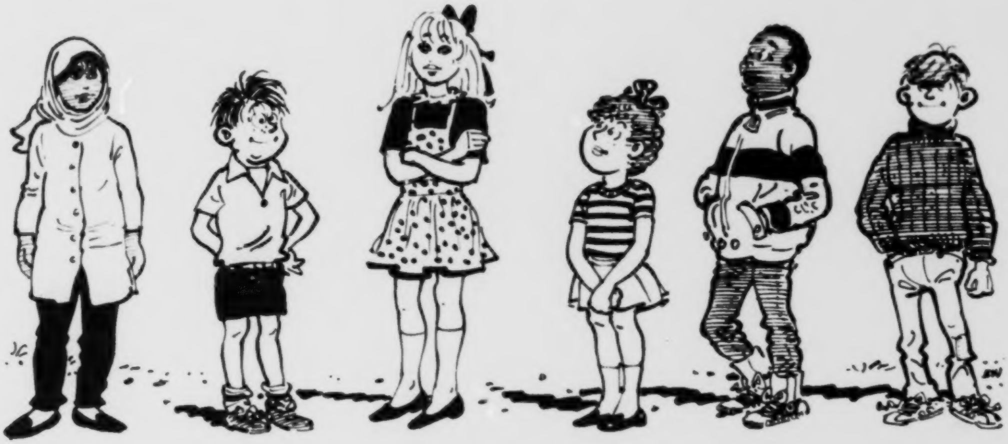


Fill in the table in your Worksheet (part 3), and answer the questions underneath it.

Activity 2: Workcard D **Variables**
Two variables

4 *Height and weight*

Here are pictures of six children:



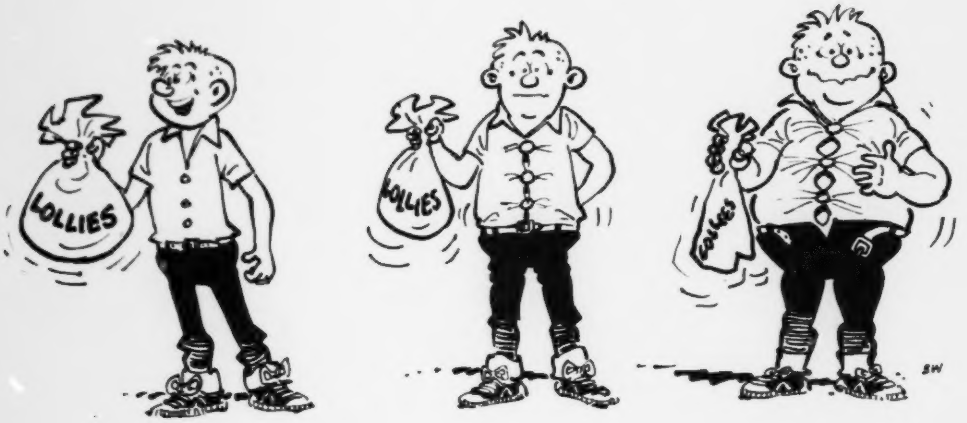
	Veena	Clark	Sharon	Susan	Robert	Lee
height:	148 cm	146	151	142	149	144
weight:	43 kg	31	38	35	34	42

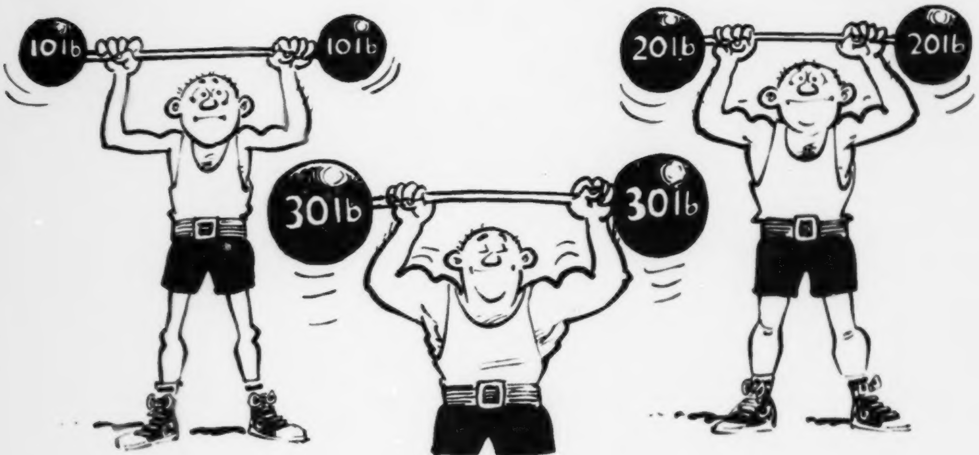
The height (measured in centimetres) and the weight (measured in kilograms) of each person is written under their picture.

On your Worksheet (part 4), complete the table. Put each person in order of height, with the shortest first and the tallest last.

When you have completed the table, answer the questions.

Activity 2: Example Card
Two variables


LOLLIES
LOLLIES
LOLLIES


10lb
10lb
20lb
20lb
30lb
30lb

Workcard Answers

A

1 For example: one tube fat, long, glass and the other narrow, long, glass (length and material the same, width different). There would be no difference in the notes.
2 A short one. Width and material are irrelevant.
3 Any design that includes closed end/open end as the *only* difference in a comparison between tubes of the same length (same material and width may be specified also).
4 The short ones give the highest notes.
No, because width does not make an difference to the note (although it might make a difference to the loudness that can be achieved).

B

1 No, because the boy and girl did not start at the same place. (This is not an example of control of variables in the sense required for normal thinking.)
2 Yes is an acceptable answer, because other variables are not mentioned and implicitly are controlled.
3 Yes, this is a good test; other variables such as type of shoe leather are controlled by cleaning left and right shoes from the same pair with different polish.
4 No, because he should have used the same heat underneath each.
5 No, all should drop on the same surface.
6 Yes, as far as we can tell from the picture variables such as density of application and equivalence of plots are controlled.
7 Yes, as far as we can tell the surfaces over which they travel are the same and they all start at the same place and time.
8 Fair enough, provided he walks on the same surfaces at the same speed, but what a silly way to test for bag strength! (You might ask pupils to design a better test.)

Activity 3: The 'fair test'

Introduction

This experiment involves three input and one outcome variable. Relationships and non-relationships are brought out. The 'control of variables' strategy is *not* specifically described, but the notion of a 'fair test' is built on, with the intention that pupils themselves discover the need to control variables. A series of fair test problems is provided for follow-up or homework.

Apparatus summary

For whole class

- Lengths of tubing: plastic and glass; 'long', 'medium', and 'short'; 'wide', 'medium', and 'narrow'
- Disinfectant

Per pupil

- Worksheet
- Workcard

Procedure summary

1 Demonstrate blowing across tubes to get notes. The experiment is to investigate the effects of variables on the note produced.

2 Allow free experimenting for a few minutes. Dip the tubes in disinfectant between blows.

3 Elicit variables and values involved: material (glass/plastic); length (long/medium/short); and width (wide/medium/narrow). Pupils try the tubes in pairs.

4 Ask whether particular pairs of tubes provide fair tests.

5 Question conclusions, maybe try more pairs of tubes.

6 Summarise, looking at one variable at a time. Relate to examples from other science activities.

7 Pupils work on problem Workcard.

Procedure details

1 Show how you can get a note by blowing across one of the tubes. Demonstrate notes with three different tubes. What makes the tubes give different notes? The experiment is to investigate what affects the highness or lowness of the note produced.

To be hygienic, the tubes should be dipped in disinfectant before blowing across them.

2 Let each group experiment freely with the tubes, starting with three different ones for a few minutes.

3 Now ask what are the different variables involved, and what are their values. Elicit material (glass/plastic); length (long/medium/short); and width (wide/medium/narrow). In other words, there are three input variables. The task is to find out which, if any, of these input variables effects the note (outcome). Emphasise that they should try the tubes in *pairs*, comparing the note produced by each. Refer to the Worksheets, and where necessary help pupils to complete them.

4 Go around groups as they work, asking about fair tests, whether a particular pair of tubes is useful to reach a conclusion, and what conclusions can be drawn. 'What have you found?' 'Which pair of tubes tells you that?' 'Are you sure?'

5 After they have done about four pairs, they should try to reach a conclusion. Question this and if necessary suggest that they try some more pairs of tubes. It might help to demonstrate with a long narrow glass tube and a short wide glass tube, saying 'that shows wide tubes give a higher note, doesn't it?' Keep your fingers crossed that someone will contradict you, allowing discussion on the notion of a fair test. It also helps to ask individuals or groups what particular pairs of tubes 'prove' their conclusion to be correct.

6 When all apparatus and Worksheets have been collected, summarise the experiment in terms of looking at one variable at a time. This is important in any scientific investigation. Draw examples from their regular science course where experiments like this have been done, or will be done soon. Emphasise the need to think about variables whenever they do an investigation.

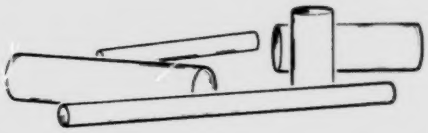
7 Refer to the Workcard, and while pupils work on them individually, go around and discuss difficulties as they arise. If your pupils do homework, they could take the problem sheets home.

Your name: ....

Activity 3: Worksheet
*The 'fair' test

Variables

Take *two* tubes.
Blow across them and compare the notes you get.
Record your results in the table.
Do the same for other *pairs* of tubes.



Tubes		Material (glass or plastic)	Length (long, medium or short)	Width (wide, medium or narrow)	Which note is higher? Or are they both the same?
1st pair	a				
	b				
2nd pair	a				
	b				
3rd pair	a				
	b				
4th pair	a				
	b				

Can you say yet how each of the input variables affects the note?

1 What is the effect of *length*? .... Which experiments tell you this? ....

2 What is the effect of *width*? .... Which experiments tell you this? ....

3 What is the effect of *material*? .... Which experiments tell you this? ....

If you are still not sure, try some more *pairs* of tubes. Record your results on the back of this sheet.

Activity 3: Workcard
The 'fair' test

Variables

A High notes, low notes

You have just done some experiments to find out which variables affect the note you get when you blow across a tube. Now answer these questions:

1 Janice says that fat tubes make lower notes than thin tubes. Describe (material, length, and width) just *two* tubes that you would choose to demonstrate to Janice that she was wrong (or right?).

What result would you expect?

2 If you wanted a tube that would give a very high note, what sort of tube would you choose?

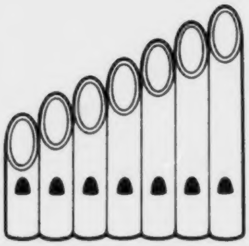
3 Describe a test or tests you would carry out to investigate the effect of closing one end of the tube.

4 Here are some of the pipes of an organ in a concert hall.

Which pipes give the high notes?

Do all the pipes have to be the same width?

Give a reason for your answer.



▶

B *Some 'fair' tests?*

1 During a school sports afternoon it was decided to see if boys ran faster than girls. John and Jane were timed during this race, they both started to run at the same time.

Jane
John
FINISH
Time keeper
Start
Start

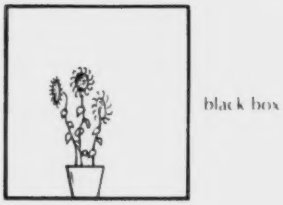
Is this a fair race?

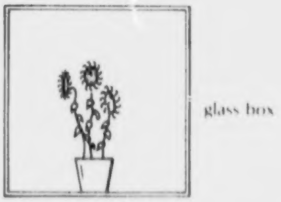
If not, why not?

2 Sohail wanted to see if sunflowers grew better in the dark or the light. He started to grow two lots of flowers, one in a dark box, one in a light box.

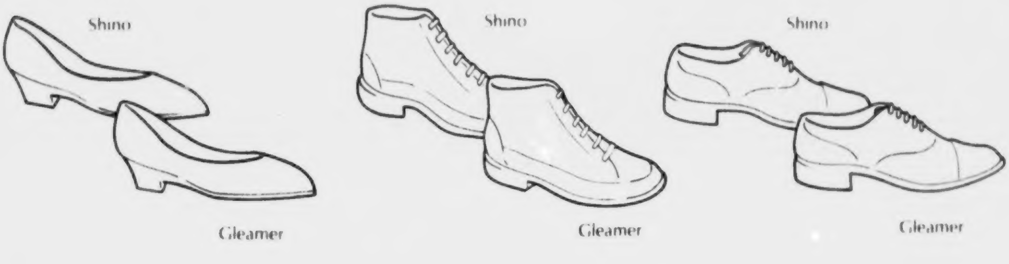
Will this be a fair test?

If not, why not?





3 Mrs Scott wanted to see if Shino was a better polish than Gleamer so she cleaned everyone's shoes in class like this:


Shino
Shino
Shino
Gleamer
Gleamer
Gleamer

Would this be a fair test?

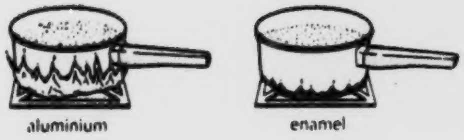
If not, why not?

▶

4 When Jack wanted to see if aluminium pans cooked food faster than enamel pans he did this:

Was this a fair test?

If not, why not?


aluminium
enamel

5 Sarah wanted to see which object bounced highest so she set up an experiment like this:

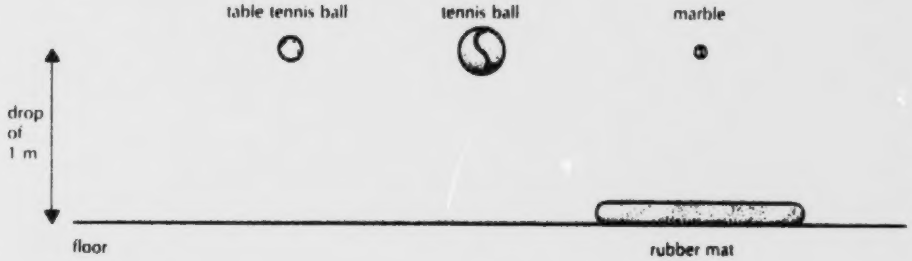
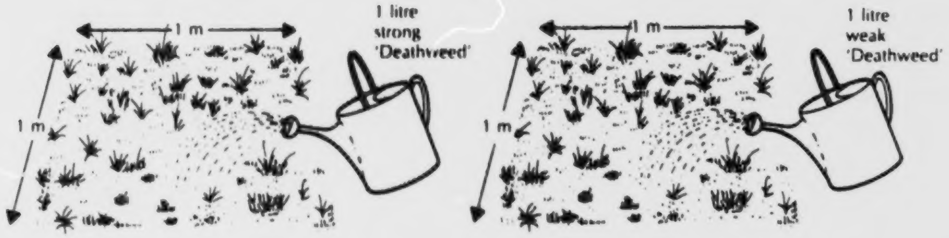


table tennis ball
tennis ball
marble
drop of 1 m
floor
rubber mat

Is this a fair test?

If not, why not?

6 Miss O'Brien watered two patches of lawn with a weedkiller 'Deathweed', to compare its weedkilling powers at two different strengths:


1 m
1 m
1 litre strong 'Deathweed'
1 m
1 m
1 litre weak 'Deathweed'

Has she made a fair test?

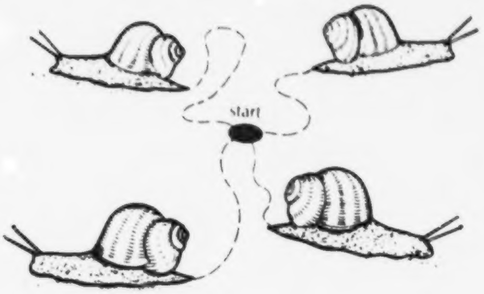
If not, why not?

▶

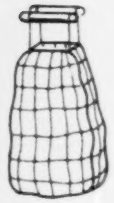
7 Sharon had a snail race to see which one of her pet snails was the fastest. She saw how far they had gone after 30 minutes:

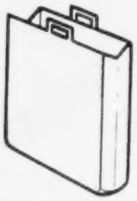
Was this a fair race?

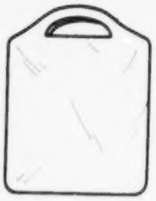
If not, why not?

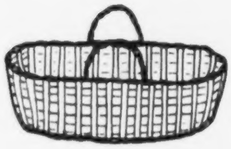


8 Tariq wanted to see which type of material makes the strongest shopping bag so he carried around ten tins of dog food in each of these bags and timed how long it took for each one to break.


string


paper


plastic


straw

Was this a fair test?

If not, why not?

Activity 4: What sort of relationship?

Variables

Introduction

Two experiments are done in which one variable is related with another. In one experiment (spring extension vs. weight) the relationship is linear and direct; in the other (oil thickness vs. temperature) it is curvilinear and inverse. These are modelled by plotting graphs, and the activity provides a specific opportunity to relate the shape of a graph to the nature of a relationship. From the pupils' point of view, in one experiment the variables go up together and give a straight line; in the other one goes up as the other goes down, and the line is curved. It is easier to make predictions from the first type than from the second.

The two experiments are written here as activities for pupils to carry out in groups. In practice there would not be time for this, so one should be demonstrated. Which one you choose depends on whether the class has already done one of them, and what apparatus you have available.

Apparatus summary

- Retort stand with clamp, spring, weight hanger and weights, rulers. Workcard A
- Engine oil, funnel, beakers, Bunsen etc, thermometer, stop clock, Workcard B
- Worksheet

Safety point Check that you know the location and usage of the asbestos blanket, carbon dioxide, or other fire extinguisher suitable for oil fires.

Procedure summary

1 For the pupils' activity, elicit relevant variables and values (spring extension and weight or oil temperature and thickness). Help them as necessary to carry out the experiment.

2 They will probably need help plotting the graph.

3 Do the demonstration, pupils complete the table and plot the graph.

4 Pupils compare the two graphs, and discuss conclusions. A straight line relationship allows predictions to be made.

Procedure details

1 Pupils are to investigate two different sorts of relationships between variables. For the activity they are going to do, check that names of apparatus are known, describe what they are going to investigate, and elicit relevant variables and values (spring extension and weight; or oil temperature and thickness). **Refer to** Worksheets and help groups as necessary to follow the instructions.

2 Pupils will almost certainly need help with plotting the points for the graph. If you try out the activities in advance you will be able to advise on good values to put in on the axes.

3 When the pupil experiment is complete do the demonstration, letting pupils complete the table and plot the graph. **Use a copy of** the Worksheet graphs to show them how to plot points.

4 Now you have the raw data, displayed in a graphic form. Discuss the two graphs with pupils, asking them to compare them. One is straight and one is curved. This says something about different sorts of relationships in the two experiments. Spring extension is related to weight by a straight line. If you added an extra weight, what would be the extension (or total length)? It is quite easy to work it out from the graph, making the line a bit longer. This is not nearly so easy with the curved temperature/thickness line. Straight line relationships allow predictions to be made.

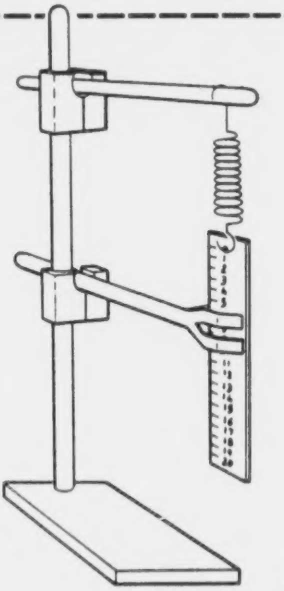
Another difference between the graphs is that one goes up to the right, the other goes down to the right. This is a picture of the difference between 'they both go up together' and 'one goes up when the other goes down'.

Your name: ....

Activity 4: Worksheet
What sort of relationship?

Variables

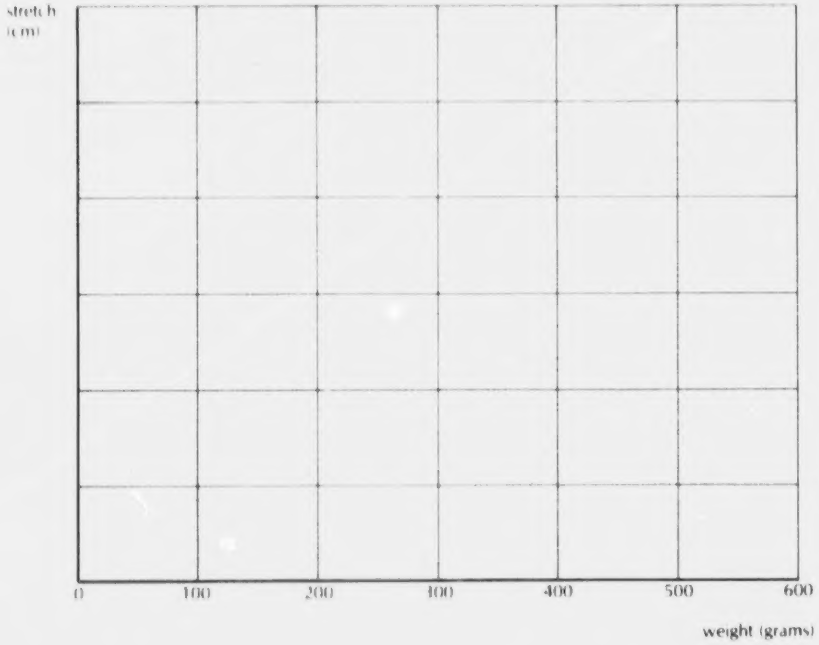
1 *Stretching a spring*



Record your results in this table:

Weight	Stretch of spring
0 g (no weight)	0 cm
100 g (hanger only)	. . . . cm
200 g	. . . . cm
300 g	. . . . cm
400 g	. . . . cm
500 g	. . . . cm

Graph of stretch against weight.

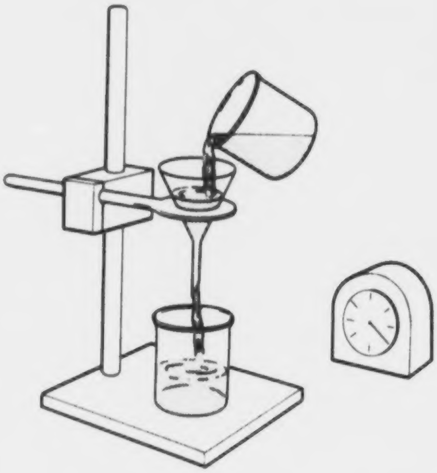


Your name: ....

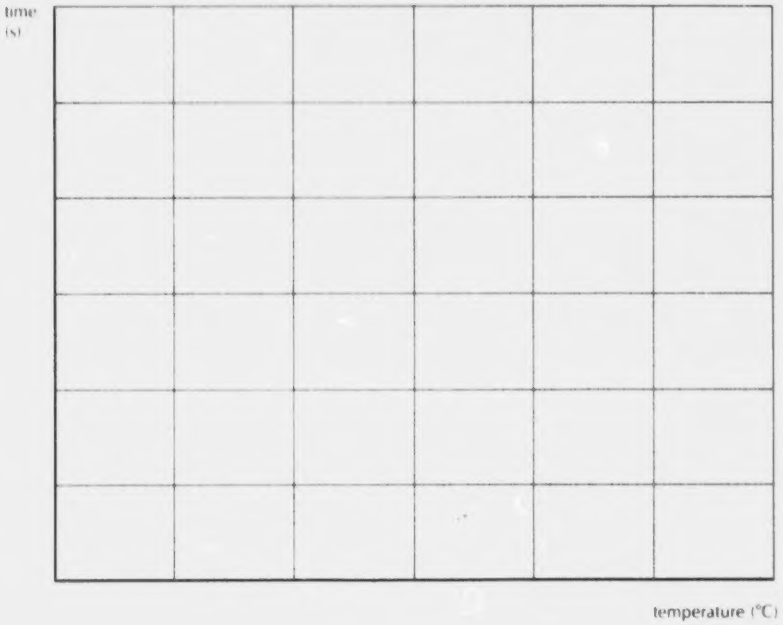
2 *Heating oil*

Record your results in this table:

Temperature (°C)	Time taken for oil to pass through funnel (seconds)



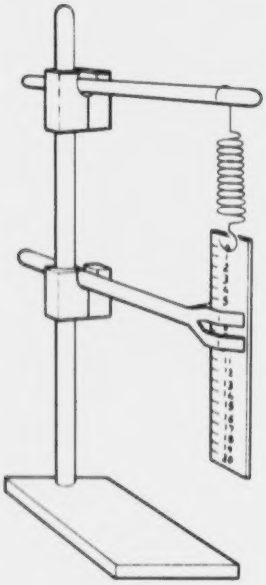
Graph of time against temperature.



Activity 4: Workcard A What sort of relationship?

Variables

Stretching a spring

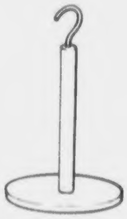


1 Hang a spring on a stand.

Clamp a ruler behind it so that the bottom of the spring is just in front of the 0 cm mark on the ruler.

2 Hang a weight hanger on the spring.

The hanger weighs 100 g.



Read off the ruler how far the spring has stretched.

Write the result in the table on your Worksheet.

3 Add a 100 g weight to the hanger.

The total weight on the spring is now 200 g (100 g weight and 100 g hanger).

Fill in the next line of your table.

4 Go on adding weights, 100 g at a time, until the total is 500 g.

Write the stretch of the spring for each weight in your table.

5 Plot the readings on the graph on your Worksheet.

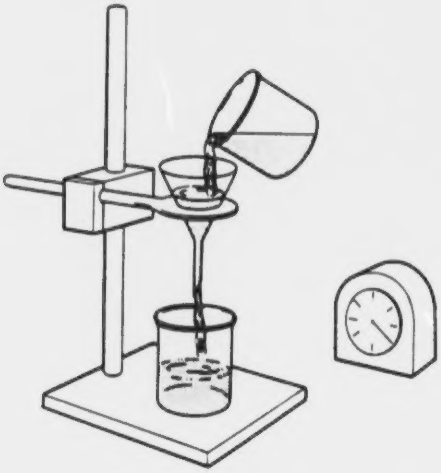
Activity 4: Workcard B
What sort of relationship?

Variables

Heating oil

1 When cooking oil gets hot, it gets thinner, more runny. The same thing happens to engine oil, used in cars.

In this experiment, you are going to investigate how much runnier oil becomes as it is heated.

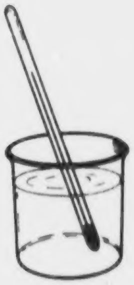


2 When oil is thick it takes a long time to go through a funnel.

When it is thin, it runs through quickly.

You can measure the time taken for oil to run through a funnel.

The time taken will be a measure of its thickness.



3 You have 100 cm^3 of oil in a beaker.

Use the thermometer to measure its temperature.

Write the temperature in the table on your Worksheet.

4 When you are ready, one person says 'now!' and starts the clock. Another pours the oil through the funnel.

Stop the clock as soon as all the oil has gone through.

Write in the table on your Worksheet how many seconds it takes.

▶

5 Now put the beaker of oil on a gauze on a tripod.

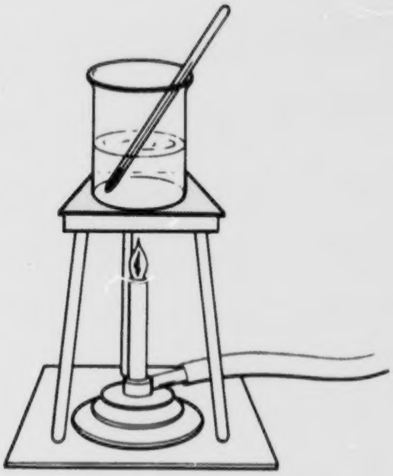
Light the Bunsen burner, adjust it to a small flame, and put it under the oil.

Warm the oil for a *short* time.

Stir it gently with the thermometer until the temperature is about 30 °C

Write the temperature in the table on your Worksheet.

Pour the warm oil through the funnel and time it just as you did before.



6 Repeat the experiment, but each time make the oil a bit hotter.

Try temperatures of about 40°, 50°, 60°, 70°C.

7 When you have five or six readings, plot them on the graph on your Worksheet.

Activity 5: Roller ball

Variables

Introduction

Still without specifically mentioning 'control of variables', pupils work with a multi-variable problem in which variables must be controlled if any sensible result is to emerge. The apparatus is introduced, the class plans experiments. Experiments are demonstrated and the nature of the results considered. Some relationship problems are worked through to consolidate all of the work on variables.

Apparatus summary

For demonstration

- Track on which balls can roll (one steep end and one flat end)
- Scale board shows height from which ball is released etc.
- Balls of different materials, sizes etc.
- Top pan balance

Per pupil

- Worksheet
- Workcard plus graph paper.

Procedure summary

1 Demonstrate one 'roller' ball hitting a 'target' ball, moving it along. Show different balls and ask what sort of things could be investigated. Elicit some variables and values for 'roller' ball and for 'target' ball.

2 Demonstrate a few 'experiments' with confounding variables and/or investigating non-effective variables. e.g.
- brass vs. steel roller ball, released from different heights.
- effect of colour of marble, on different targets.

What conclusions can be drawn?

3 Pupils work on the planning part of Worksheets.

4 Experiment with the effect of height of release of roller on distance travelled by target. Class records results. Can predictions be made?

5 Try effect of roller balls varying in mass, size, colour, from the same height. What, if anything, can be concluded?

6 Pupils do 'relationship' problems on Workcard.

Procedure details

1 Show how one roller ball released from the raised end will hit a target ball resting at the bottom and move it along. Show that you have a number of different balls, without specifying ways in which they are different, and ask what sort of things could be investigated with this apparatus (or 'what would you like to try out?')

Elicit some variables: Size, weight, colour, material of roller ball, and same for target ball. Height of release and/or distance from release point to target. Height/distance target reaches. Any other possibilities that are mentioned.

2 Now demonstrate a few experiments, but without results recorded, and in each case confounding variables. For instance
- Effect of brass vs. steel roller ball, but with rollers released from different heights.
- Effect of colour of marble, but on different targets.

Ask what conclusions can be drawn, query incorrect answers, but do not labour the point.

3 Refer to planning Worksheet and allow pupils to work on them individually. Probe with questions to individuals and groups.

4 After about ten minutes, do a first experiment (with pupil help) into the effect of height of release of roller on distance travelled by target. Use two balls of similar mass. The class records each result in the table on their Worksheet and make a point on the graph at the same time. What sort of relationship emerges? Does it become possible to make predictions of the distance that the target will travel from the height the roller is released?

5 The next experiment is the effect of different roller balls on the distance to which the target goes. Release each from the same height. Pupils record results in a table. What does this tell us? Not a lot, because these balls differ from one another in different variables: size, weight, colour. Whether you leave this open-ended or get pupils to suggest a good test will depend on how much time you have.

6 Refer to the 'relationship' problems, and explain what they have to do. These could be worked through at the end of the lesson or as homework.

Workcard Answers

1 a Weight b Volume c B
2 C
3 a A b Volume setting c Loudness
4 A
5 a A b *d*
6 In both, output and input go up together, but 4 gives a curve, 5 a straight line.

Your name: ....

Activity 5: Worksheet Roller ball

Variables

Planning experiments with the roller track

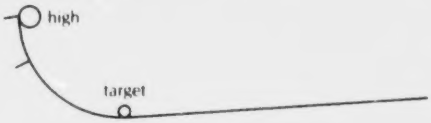
When the *roller* ball is released, it hits the *target* ball. You have to plan experiments to investigate the variables that determine how far the target ball is pushed along.

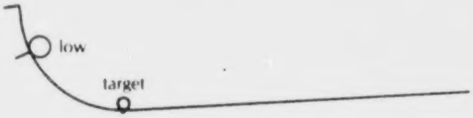
Suppose that you have:

three large balls: 1 lead, 1 brass, 1 steel
one medium sized steel ball
one small steel ball
three large glass marbles; one is red, one blue, one yellow.

1 You might want to find out whether it makes a difference to release a roller ball from a *high* or a *low* position.

Look at these drawings and decide *which ball* you would release from the *high* and *low* positions, to find out whether *height* makes a difference.





Which ball would you release from the *high* position? ....

Which ball would you release from the *low* position? ....

Please explain your answer:

....

....

....

2 Suppose that someone releases the large steel ball from the *low* position. Then which ball would you release from the *high* position in order to see whether the *height* makes a difference? ....

Please explain your choice:

....

....

....

▶

Your name: ....

3 You want to see which metal ball will hit a target furthest. You do these two experiments:

large brass

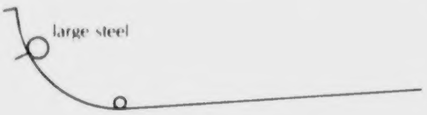
Suppose the brass ball hits its target further than the lead ball hits its target. Does this prove that brass is better for propelling any target? Please explain your answer.

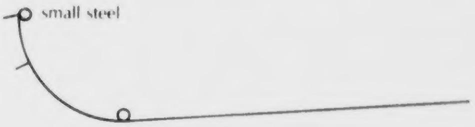
....

....

....

4 Now someone plans two new experiments shown here:





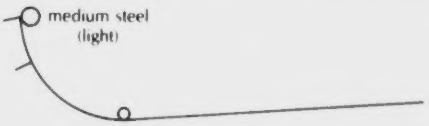
The target in the first drawing is hit further than the target in the second drawing. Does this prove that the *low* position is better than the *high* position for hitting a target far? Please explain your answer.

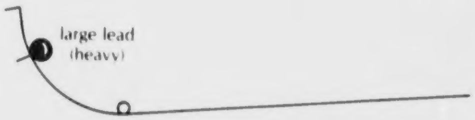
....

....

....

5 Now you want to see if the weight of a ball makes a difference to how far a target is hit. You do these experiments:





The target in the first drawing is hit further than the target in the second drawing. Does this prove that the *heavy* sphere can hit a target further than the *light* sphere can? Please explain your answer.

....

....

....

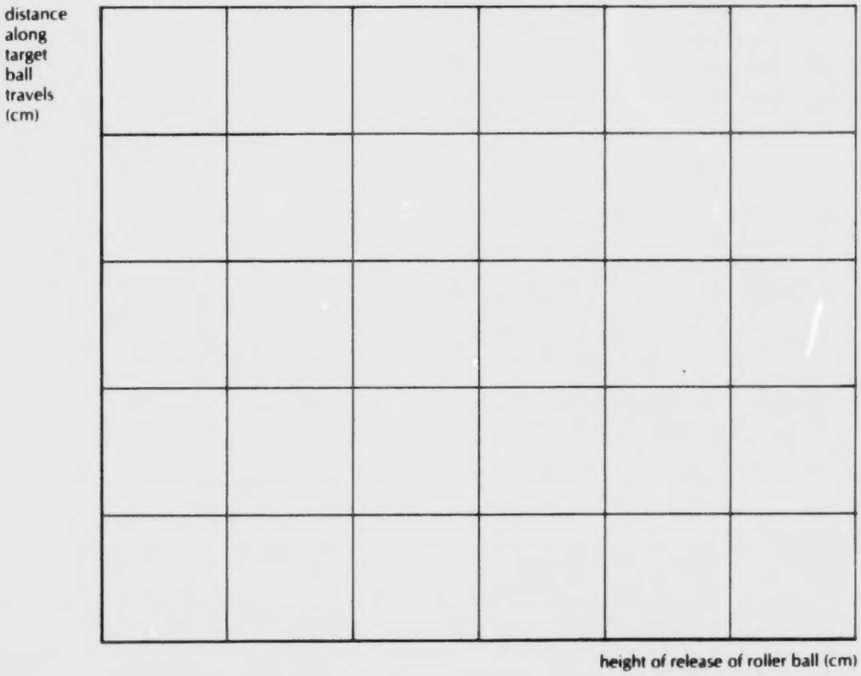
Your name: ....

Results

Record your results in this table:

Input variable Height from which roller ball released (cm)	Outcome variable Distance along travelled by target ball (cm)
....	....
....	....
....	....
....	....
....	....
....	....
....	....
....	....

Graph of target ball distance against roller ball height.



Activity 5: Workcard **Variables**

Roller ball

What sort of relationship?

These problems show the results of some experiments. Each table shows values of two variables.

Use these codes for types of relationships:

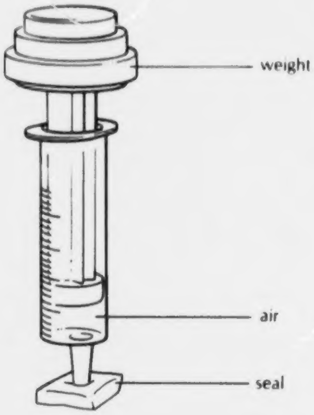
A – if the values of the two variables go up together;
B – if the value of one variable goes up while the other one goes down; or
C – if there is no relationship between the variables.

Sometimes it will help to copy out values in a better order.

1 Samantha seals the end of a plastic syringe. She loads weights on the top.

For every weight she adds, Samantha notes the volume of air in the syringe. These are her results:

Weights added (kg)	Volume of air (cm^3)
0	50
0.5	46
1.0	42
1.5	38
2.0	34
2.5	30



a Which is the input variable?
b Which is the outcome variable?
c What sort of relationship is there, A, B, or C?

2 Jim's aunt says 'When there are a lot of berries on the holly, it will be a cold winter'.

Jim tries to find out if this is true. Each year for five years he counts the number of berries on his aunt's holly bush. He also records the average monthly temperatures for December, January and February. These are his results:

Number of berries	Average winter temperature (°C)
2300	2.0
3500	5.0
750	3.0
1500	0.5
4200	1.5

What sort of relationship is there, A, B, or C?

►

3 Horace uses a loudness meter to check the volume control of his stereo system. He measures the loudness (in decibels) for each setting of the volume control. These are his results:

Volume setting	Loudness (dB)
1	1.0
2	5.0
3	6.5
4	7.0
5	7.2

a What sort of relationship is there, A, B, or C?
b Which is the input variable?
c Which is the output variable?

4 A survey is carried out to find out how much petrol is used by different size cars, all doing the same sort of journeys. These are the results:

Weight of car (kg)	Rate of using petrol (litres/km)
950	0.12
650	0.09
1250	0.17
800	0.10
500	0.08
1100	0.14

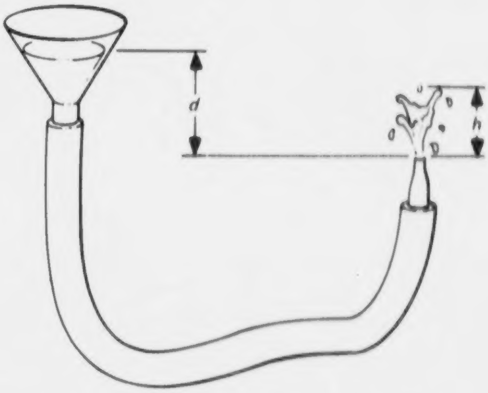
What sort of relationship is there, A, B, or C?

5 Siti joined a funnel to a jet with a rubber tube. When she puts water in the funnel, it makes a fountain out of the jet. The height of the fountain depends on how high she holds the funnel.

Siti measures the distance between the water level and the jet (she calls this *d*), and she measures the height of the jet (she calls this *h*).

Here are her results:

d (cm)	*h* (cm)
10	5
20	10
30	15
40	20
50	25



a Is this a relationship type A, B, or C?
b What is the input variable?

6 Plot graphs of the results in 4 (car weight/petrol) and 5 (water/height). In what ways are the relationships the same? In what ways are they different?

Activity 6: Gears and ratios

Introduction

Simple ratios are of the form 1:x or 2:x. In other words, they involve just two numbers, at least one of which is a small integer. Ratios are an essential precursor to proportions. In this lesson, starting from a practical example of gear or pulley ratios, we go through some demonstrated examples (scale models, dolls, maps) and end up with another practical scaling **problem:** finding the thickness of a piece of paper. All ratio problems are easier if the ratio is a whole number. You will have to judge how difficult to make your examples according to the age and ability of your class.

Apparatus summary

Per group

- A pair of gears or pulleys, copy of map, 10 pennies, pad of paper, ruler

For demonstration

- Scale model car, or train, etc., 'Barbie' doll, 'Action Man', etc.

Per pupil

- Worksheet
- Workcard

Procedure summary

1 Pupils work through first part of the Worksheet, using different gear sets.

2 With scale model train, car, etc, explain constant ratio between size of any part and the size of the corresponding part of the real thing. Scaling up calculations with whole and parts of the model.

3 Give out map, explain its scale, and do some examples converting centimetres on the map to kilometers (or miles) in reality.

4 Second part of the Worksheet: let them do as much as they can by themselves.

5 If you have time move on to the Barbie Doll/Action Man. Class works out the ratio of leg length to total height, compares with same ratio on themselves.

6 Problems on ratio (Workcard).

Procedure details

1 Demonstrate the gear apparatus and let them get on with the first part of the Worksheet. Discuss the problem as necessary, individually and with the whole class. When two groups have finished with one pair of gears, they can swop.

2 Produce your model train, car, or whatever, and explain that this is a **scale** model – there is a constant ratio between the size of any part of the model and the size of the corresponding part of the real thing. Write up the scale of your model, measure its length, and go through the scaling up calculation to find the length of the real thing. Do the same thing with parts of the model, getting the class to do the sums; and some in reverse, e.g. 'If the windscreen in the real car is 120 cm wide, how big should it be on the model?'.

(In one project school, the teacher brought her **real car** up to the door of the lab so the class could measure it!)

3 Now give out the map, explain about its scale, and do some examples converting 'centimetres on the map to kilometres (or miles) in reality. Pupils can find where they live, or a place they know, and work out how far it is from the school.

4 Move now to the second part of the Worksheet, letting them do as much as they can by themselves.

5 If you have time (some classes get through the work above quite quickly), you can move on to the Barbie Doll/Action Man. Measure its leg length (heel to hip) and total height. Get the class to work out the ratio. Now get them to do the same thing on themselves, working in pairs. What should emerge is that the so-called 'lifelike' doll actually has a ratio of leg length to body height far greater than any real person. (This is an introduction to proportions, since we are comparing two ratios.)

6 **Refer to the Workcard** problems on ratio. These can be done if there is time at the end of the lesson, or as homework.

Workcard Answers

1	10 coins	4b	15 turns	6	1:5	7c	4000 rpm
2	300:600 = 1:2	4c	8 turns	7a	1:40		
3	250 boys	4e	150 turns per minute	7b	3200 rpm		

Your name: ....

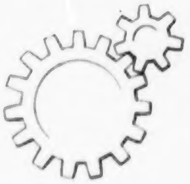
Activity 6: Worksheet Gears and ratios

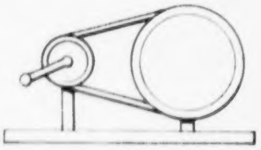
Proportionality

1 Gears

Use a pair of gears or pulleys to answer questions 1–5.

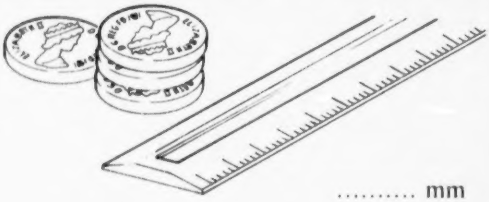
Repeat with another pair.





	1st pair	2nd pair
1 How many times do you have to turn the small wheel to make the large one turn *twice*?	....	....
2 *Without doing it*, work out how many times the small wheel would turn if you turned the large one *once*.	....	....
3 Now try it, and check if you were right.		
4 The **ratio** of the number of turns of the big wheel to the number of turns of the small wheel is	1:	1: ....
5 If the large wheel turned 20 times in a minute, how fast would the small wheel turn?	....	....

2 Paper thin



6 You have a pile of pennies.

Measure the thickness of *one* penny, as accurately as you can:

How did you do that? .... mm

7 Use the same method to measure the thickness of one sheet of paper. .... mm

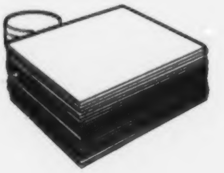
8 What is the **ratio** of the thickness of the paper to the thickness of the penny? 1: ....

Activity 6: Workcard

Proportionality

Gears and ratios

Problems



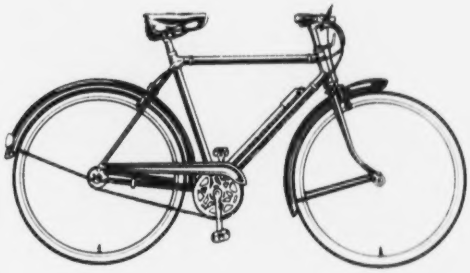
1 Four hundred pieces of paper are the same height as a pile of coins.

If the ratio of paper thickness to the thickness of one coin is 40:1 how many coins are there in the pile?

2 In my school there are 900 pupils, but only 300 are girls. What is the ratio of girls to boys?

3 There are 750 pupils in my friend's school and the ratio of girls to boys is 2:1. How many boys do you think there are?

4 'The ratio of peddle turns to wheel turns of a bicycle is 2:5'



a What does this mean? (Put the sentence in your own words.)

b If the peddles are turned six times how many times will the wheel turn?

c If the wheel has turned 20 times how many times have the peddles turned?

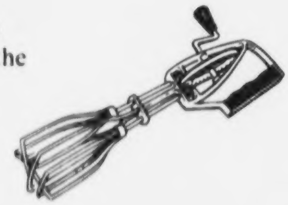
d Which is turning fastest, the peddles or the wheels?

e If the peddles are turned 60 times per minute, how fast is the wheel turning?

5 Use the word **ratio** to write a sentence which tells me that I need three times as much sand as cement to make concrete.

6 The whisks on a hand egg beater turn 300 times a minute when the handle is turned 60 times per minute. What is the ratio of handle turns to whisk turns?

Why do you think an egg beater is made like this?



7 When the engine of a car is turning 4000 times per minute (rpm), the car is moving on the road at 100 miles per hour (mph).

a What is the ratio of mph to rpm?

b What speed would the engine be turning if the car was moving at 80 mph?

c At 80 mph, the driver changes down a gear. The new ratio of mph to rpm is 1:50. What is the speed of the engine now?

Activity 7: Scaling: pictures and microscopes

Introduction

This lesson puts scaling into a biological context and reinforces the calculation of ratios. Diagrams of human embryos are used to illustrate 'scaling up' and 'scaling down'. Students use a microscope and see magnification as a scaling up process.

For the second part, students need to have had experience with microscopes. If they have not, you could either put in a special lesson introducing microscopes before this activity or leave the activity until after you have introduced microscopes in the course of your normal curriculum. A third alternative is to use the first part on scaling drawings, and extend it with examples from text books etc. Then construct a fuller lesson which both introduces the use of microscopes, and deals with the scaling aspects outlined in the second part of this intervention lesson.

Apparatus summary

Per group

- Microscope, slides and coverslips, forceps
- Transparent ruler or graph paper sellotaped to slide

Per class

(Optional – you may find that only more able classes will get as far as this)

- Onion, filter paper, iodine, dropper

Per pupil

- Worksheet
- Workcard A
- Workcard B

Procedure summary

1 Discuss the need to reduce or enlarge drawings, photographs etc. Pupils assess whether drawings of embryos have been scaled up or scaled down, and by how much (first three columns of the first table on the Worksheet). Use the word **ratio**.

2 The magnifying power of the microscope: **total** power = power of eyepiece × power of objective.

3 Students 'guesstimate' the diameter of a hair, using a transparent ruler (or a slide with graph paper) under the microscope.

4 (More able classes) Estimating the size of an onion cell from width of field of view at low power and number of cells visible at that power.

5 **Problems on scaling (Workcard B).**

Procedure details

1 Scale Drawings. Discuss the need to reduce or enlarge drawings, photographs etc., to fit on a page or to show detail. This is particularly important for many biological drawings and photographs.

On the Workcard A drawings, embryos a and **b** are still in the womb and **c** is just born i.e. has had nine months development. Students are asked to assess if each drawing has been 'scaled up' or 'scaled down' i.e. are they larger or smaller than life? How could one calculate how much bigger or smaller the drawings are compared with the real embryos? Students measure the length of each drawing (lines a.b.c.) and fill in the first three columns of the first table on the Worksheet. Illustrate the first calculation using the word **ratio**. Students should then continue to complete the table on their own.

Age of embryo	Drawing/Real size	Scale
6 weeks	60/12	× 5
3 months	135/45	× 3
9 months	90/360	× 1/4

The last one is difficult. It helps to ask 'is the drawing bigger or smaller than a real baby?', and 'what would you have to multiply the size of the real thing by to get the drawing?'

2 The magnifying power of the microscope. Explain that **magnification** is like scaling up so that small things look big. The total **magnifying power** of a microscope is the magnification of the eyepiece multiplied by that of the objective.

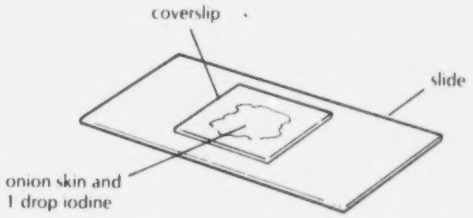
3 Students use a transparent ruler (or a slide with graph paper) to measure the diameter of the field of view (Workcard section 3). Then the width of a hair can be estimated from the proportion of the field of view occupied. The exercise is intended to give the students a feel for magnification.

4 Estimating the size of an onion cell. (You may find that only more able classes get this far.) Get a thin layer of onion skin by breaking a segment of the fleshy leaves that make up the onion bulb. The epidermis is a thin clear membrane that can be detached easily using fingers or forceps. The membrane is robust and students can use their fingers and forceps to spread a flat layer **onto a glass slide.** One drop of iodine is added to make the cells easier to see and a coverslip is put on. Gentle blotting will remove most of the air bubbles.

The length of one cell is estimated from the width of field of view and the number of cells visible. The answer can be left as a fraction of a mm or converted to decimals. The unit of **micrometer** could be introduced if this measurement is used elsewhere in the main science curriculum.

1 micrometer (μm) = 1/1000 mm

5 Workcard B has problems on scaling.



Workcard B Answers

1a Scaled up
1b About four times
1d ×4
2 ×60, ×100, ×240, ×400.
3 About 3.5 mm

Your name: ....

Activity 7: Worksheet

Proportionality

Scaling: pictures and microscopes

1 Scale drawing

a None of the human embryos is drawn 'life-size'. Why not? (See Workcard A.)

....

b Each drawing is to *scale*. Compare the real life-size length of each embryo with the size of the drawing.

Which drawings have been *scaled up* (made larger than life)?

Which drawings have been *scaled down* (made smaller than life)?

c Measure the lengths of each drawing (lines a, b, c) and write your answers in the table below. Now write the real-life lengths in the table.

The *scale* is the number of times you have to multiply the real size to get the drawing size. Work it out and complete the table.

Age of embryo	Real size (mm)	Drawing size (mm)	Scale
6 weeks			×
3 months			×
9 months			×

2/3 Microscope magnification

	Magnifying power of eyepiece (1)	objective (2)	Total magnification (1) × (2)	Width of field of view
Low power				
High power				

4 Hair

Approximate width of hair: .... mm

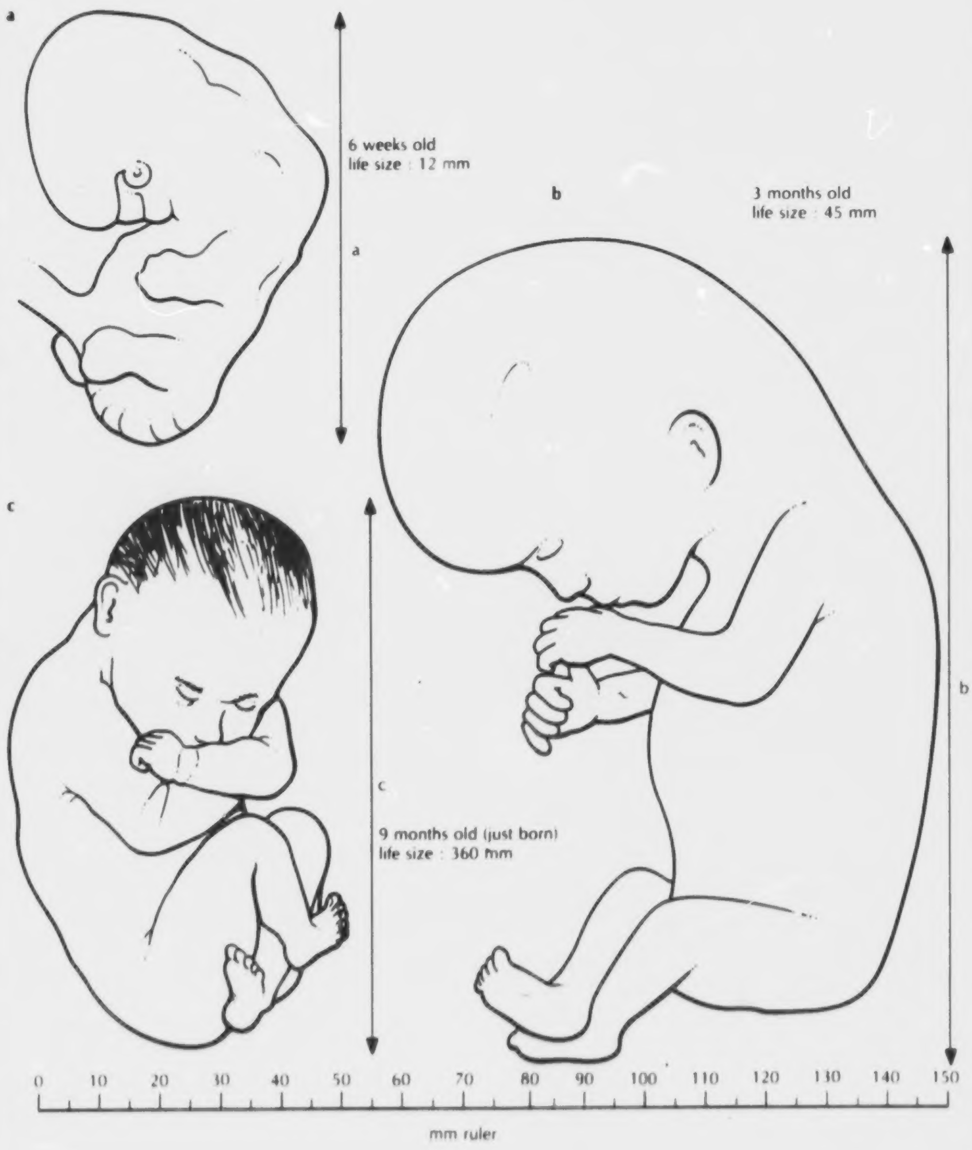
Activity 7: Workcard A

Proportionality

Scaling: pictures and microscopes

1 *Scale drawings*

Human embryos at different ages.
All drawings are to scale.

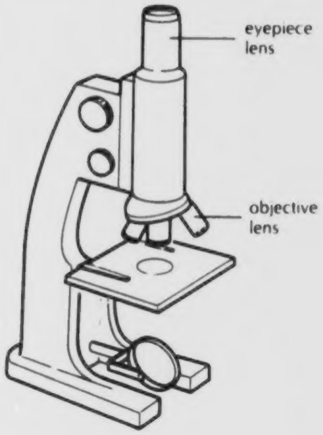

a
6 weeks old
life size : 12 mm
a
b
3 months old
life size : 45 mm
b
c
c
9 months old (just born)
life size : 360 mm
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
mm ruler

2 Microscope magnification

A microscope has two sets of lenses – the *eyepiece* and the *objective*. Your microscope may have more than one objective lens.

Find the *magnification* of the eyepiece and of the objective lens. (Look for numbers on the side of the lenses.)

Fill in the first *three* columns of the table on your Worksheet.



3 Field of view

a Put a transparent ruler on the microscope stage.

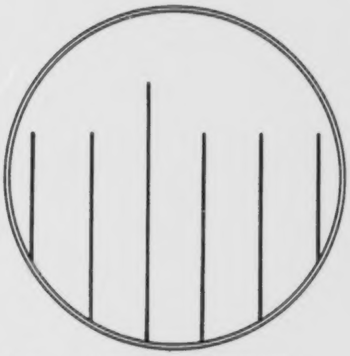
b Use the low-power objective lens and focus on the lines.

c Count how many millimetre divisions fit across the field of view.

What is the width of the field of view of your microscope?

d Write your answer in the last column of the table.

e Now do the same for a high-power objective lens.



millimetre lines in focus at low power

6 mm lines visible so this field of view is 7 mm across

4 Hair

Put a hair on a slide and look at it under *low power*. Can you work out its width? (You know how wide the whole field of view is, how much of it is filled with your hair?)

Write the answer on your Worksheet.

Activity 7: Workcard B Scaling: pictures and microscopes

Proportionality

Problems

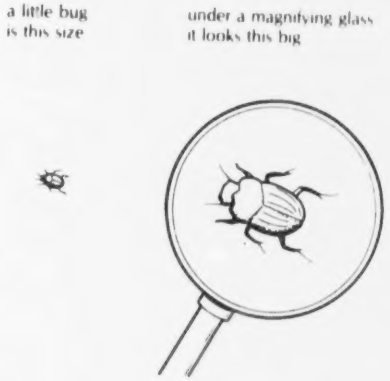
1 A magnifying glass makes things look bigger.

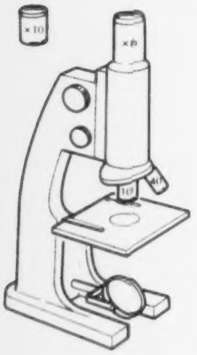
a Has the glass scaled the animal *up* or *down*?

b How much bigger has the glass made it look?

c How did you work this out?

d What is the magnification of the magnifying glass?





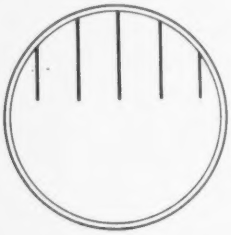
2 A microscope has:

two different eyepieces: ×6 and ×10

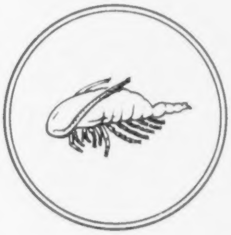
two different objectives: ×10 and ×40

What are the *four* different magnifications that the microscope can give?

3 This is what Sarah sees when she measures the field of view in mm.



This is what she sees when she looks at a water animal at the same magnification.



Work out the real length of the little water animal.

4 The drawing in question 2 is not to scale, but the drawings in questions 1 and 3 are to scale.

a What does it mean to say that a drawing is 'to scale'?

b Who might use scale drawings in their work? Why?

Activity 8: The wheelbarrow

Proportionality

Introduction

The activity starts from a familiar exercise in identifying variables and recognising (qualitatively) the type of relation between them. The relationship is quantified by finding the ratio between effort and load for a number of different loads. The ratio is constant. This is true **proportionality**: a series of pairs of values all in the same ratio to one another. Plotting results links proportionality to a straight-line graph. A parallel exercise shows the proportionality of effort to the distance of load from fulcrum. (Note that variables are being controlled to investigate these two relationships.)

Apparatus summary

Per group

- 'Wheelbarrow' made of dowel grooved and marked as shown in the **Appendix**
- 10 N spring balance (force measurer)
- Weight hanger and slotted weights (including a 50 g)

Per pupil

- Worksheet and (optional) graph paper
- Workcard

Procedure summary

1 Discussion of use of wheelbarrows. Show model and how to measure force to lift load directly and using 'wheelbarrow'. Pupils find load/lift pairs and calculate ratio.

2 Class discussion to focus on constant ratio and introduce the word **proportionality**. Students use constant ratio to find what lift would be needed for loads they have not tried.

3 Students plot graph. (If you did it, refer back to oil pouring and weight/spring, Activity 4.) Proportionality, straight line graphs, and the ability to make predictions all go together.

4 The second problem is of the same form, but this time it is the distance of (a constant) weight up the beam and lift force that are being recorded.

5 The sheet of wheelbarrow and lemonade problems are for pupils who finish early, and could be given for homework also **(Workcard)**.

Procedure details

1 Discuss the use of wheelbarrows. They have two advantages: as a lever system (a smaller force can be used to lift heavier loads); and because the wheel allows the load to be moved along. In this activity we concentrate on the first function only.

Show how to use a force measurer (in newton) to find the force needed to lift a load directly, and then using the 'wheelbarrow'. A 200 g mass on a hanger makes good first load (lighter loads are unduly influenced by the weight of the 'barrow' itself). Make sure pupils know what they have to do in the first section of the Worksheet. The input variable is load, always placed at the same place on the 'wheelbarrow'. You might do the first reading as a demonstration. The force measurer should be read as accurately as possible. Let them get on with it, and help groups as needed with the apparatus, recording results, and calculating the ratio.

2 What emerges is that the ratio of lift to load is constant (as far as the usual laboratory force measurer will allow). You could also use the questions in part 2 of the Worksheet as a focus for class discussion, introducting the word **proportionality**.

Once the ratio of lift to load has been found, it can be used to calculate the lift that would be needed for any load. Load/ratio = lift. This highlights the ability to *predict* a result, once a relationship has been established. Students will probably need help with the examples given in the Worksheet.

3 A graph of load against lift gives a straight line. This can be linked to proportionality and the ability to make predictions. If the oil pouring and spring/weight activities were done, you could refer back and establish that spring extension is proportional to load; pouring time is *not* proportional to temperature.

4 The **third Worksheet problem is of the** same form, but this time it is the distance of weight up the beam and lift force that are being recorded. The procedures and arguments are closely similar.

5 The **Workcard** wheelbarrow and lemonade problems are for pupils who finish early, and could be given for homework also. The first is partly worked through. It could be done in class as an example.

Workcard Answers

1 Tracey's (4 N per kg; Anna's needs 5 N to lift the same load)
2 Sugar to lemon, Rajit: 1:4, Fred 1:4. Both same sweetness.
3 Both the same. lift:load::3:1
4 Fred's sweeter. 1:2 sugar:lemon (Rajit's 1:3)
5 Both the same. 2 × the load and 2 × the lift
6 Both the same. 3 × sugar and 3 × lemon
7 Anna's. 3 × lift, 4 × the load
8 Fred's sweeter. Rajit's has 3 × sugar, but 4 × lemon juice
9 Tracey's. Anna's lift:load::3:1. Tracey's less than 3:1
10 Rajit's. sugar:lemon::1:3. Fred's has 1 sugar to > 3 lemon
11 Same sweetness. 1.5 × sugar, 1.5 × lemon.

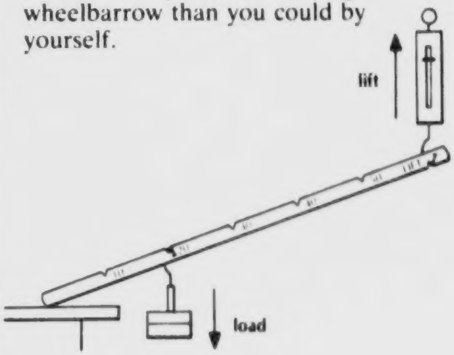
Your name: ....

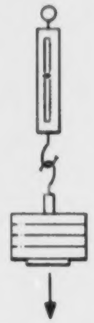
Activity 8: Worksheet The wheelbarrow

Proportionality

1 Load and lift

You can carry a lot more weight in a wheelbarrow than you could by yourself.





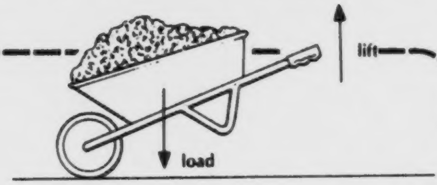
Force is measured in newtons.
The symbol for newton is N.

a Make a small load with a weight on a hanger. Find the force needed to lift it. Write this in the *load* column of the table.

b Hang the load on the *20 cm* mark on the 'wheelbarrow'. What force do you need to lift the end of the barrow? Write this in the *lift* column of the table.

c Find the ratio of lift to load: divide the load by the lift. You may need to use a calculator.

d Do the same thing for different loads.



You can use a simple beam to represent a wheelbarrow.

You can use a force measurer to find out:

- the force you need to lift a load directly
- the force you need to lift the same load, using your 'wheelbarrow'.

Load (N)	Lift (N)	Ratio load/lift

What is the input variable?

....

What is the outcome variable?

....

What do you notice about the ratio of lift to load in every case?

....

....

Your name: ....

2 *Proportionality*

When the ratio of one variable to another is always the same, we say that one variable is **proportional to** the other.

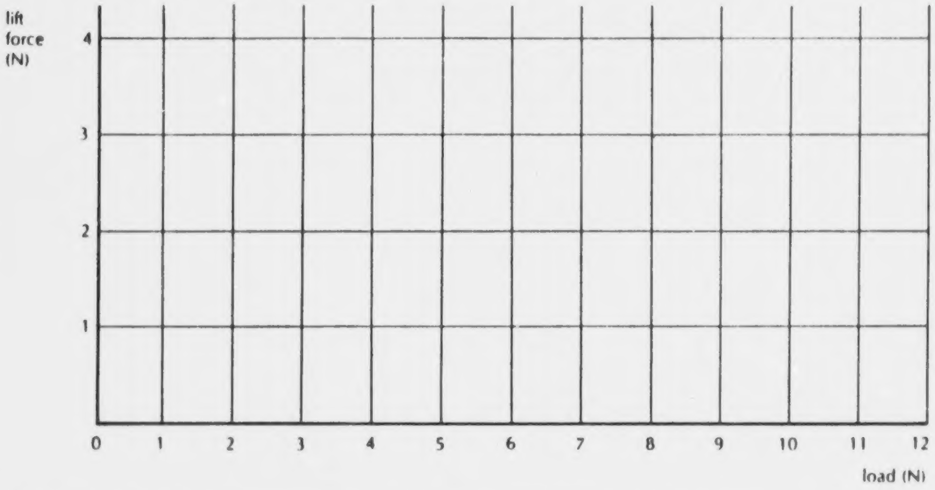
In the wheelbarrow, the lift needed is .... to the load.

Because the ratio of lift to load is always the same, you can calculate what lift you would need for loads that you have **not** tried.

With the same 'wheelbarrow', what lift would you need for each of these loads: (You may use the space on the right for calculations.)

8 N ....
10 N ....
12 N ....
15 N ....

Plot a graph of *lift* against *load*:



Variables that are proportional to one another give straight line graphs.

▶

Your name: ....

3 *Load, lift, and distance*

Is the lift you need proportional to the distance of the load from the table?

a Start again, with a load of about 3 N on the 20 cm mark. Write the force needed to lift it in the *lift* column of the table, next to the '20 cm'.

b Move the load to the *10 cm* mark. What force do you need now to lift the end of the barrow? Write this in the lift column next to the '10 cm'. Repeat with the load on the 30, 40, and 50 cm marks.

c Find the ratio of lift to distance: divide the distance by the lift. You may need to use a calculator.

Distance (cm)	Lift (N)	Ratio dist/lift
10		
20		
30		
40		
50		

Is the lift force needed proportional to the distance of the load along the 'wheelbarrow'? ....

How can you tell?

....

If you were to plot a graph of the lift against the distance, what do you think it would look like?

....

How do you know?

....

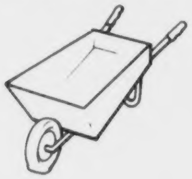
If you have time, you could check your answer by plotting the graph.

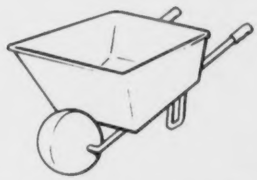
Activity 8: Workcard The wheelbarrow

Proportionality

Problems

1 Anna and Tracey each have a wheelbarrow.





Anna finds that it takes a force of 60 N at the handle to lift a load of 12 kg. With Tracey's wheelbarrow a force of 16N can lift a 4 kg load. Whose wheelbarrow makes lifting easier?

To work this out, first find the *ratio* of lift force to load for each wheelbarrow:
For Anna's barrow,

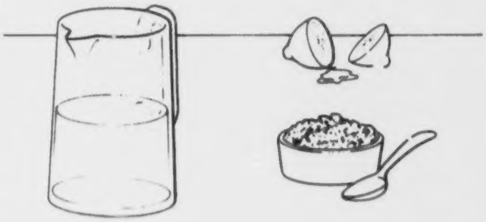
ratio of lift force to load is 60:12
which is the same as ...... 5:1 (divide both by 12)

For Tracey's barrow,

ratio of lift force to load is 16:4
which is the same as ...... 4:1 (divide both by 4)

The barrow which makes lifting easier is the one that takes a smaller force to lift the same load. So which barrow makes lifting easier, Anna's, Tracey's, or are they both the same?

2 Rajit and Fred are making lemonade concentrate by mixing lemon juice and sugar.



Rajit uses 3 spoonfuls of sugar and
12 spoonfuls of lemon juice.

Fred uses 5 spoonfuls of sugar and
20 spoonfuls of lemon juice.

What is the ratio of sugar to lemon in Rajit's juice and in Fred's juice? (Write your answer as '1:...')

How will the two concentrates taste? Will Rajit's be sweeter, or will Fred's be sweeter, or will both taste the same?

▶

Here are more 'wheelbarrow' and 'lemonade' problems like the two above but each time with different wheelbarrows or lemonade concentrates.

3 Anna needs 24 N effort at the handle to lift 8 kg.
Tracey needs 18 N effort at the handle to lift 6 kg.

Whose wheelbarrow makes lifting easier? Anna's, Tracey's, or are they both the same?

Show how you work out your answer.

4 Rajit's lemonade concentrate has 5 spoonfuls of sugar and 15 of lemon juice.
Fred's has 4 spoonfuls of sugar and 8 of lemon juice.

Whose concentrate is sweeter? Rajit's, Fred's, or are they both the same?

Show how you worked out your answer.

5 Anna needs 12 N effort to lift a 7 kg load.
Tracey needs 24 N effort to lift a 14 kg load.

Whose wheelbarrow makes lifting easier?

6 Rajit's lemonade concentrate has 2 spoonfuls of sugar and 3 of lemon juice.
Fred's has 6 spoonfuls of sugar and 9 of lemon juice.

Whose concentrate is sweeter?

7 Anna needs 24 N effort to lift 20 kg.
Tracey needs 8 N effort to lift 5 kg.

Whose wheelbarrow makes lifting easier?

Show how you work out your answer.

8 Rajit's lemonade concentrate has 9 spoonfuls of sugar and 4 of lemon juice.
Fred's has 3 spoonfuls of sugar and 1 of lemon juice.

Whose concentrate is sweeter? How did you work out your answer?

9 Anna needs 36 N effort to lift 12 kg.
Tracey needs 40 N effort to lift 15 kg.

Whose wheelbarrow makes lifting easier?

How did you work out your answer.

10 Rajit's lemonade concentrate has 5 spoonfuls of sugar and 15 of lemon juice.
Fred's has 4 spoonfuls of sugar and 13 of lemon juice.

Whose concentrate is sweeter? How did you work out your answer?

11 Rajit's lemonade concentrate has 4 spoonfuls of sugar and 10 of lemon juice.
Fred's has 6 spoonfuls of sugar and 15 of lemon juice.

Whose concentrate is sweeter?

Activity 9: Trunks and twigs

Compensation

Introduction

A qualitative introduction to the idea of compensation – one variable increasing in value as another decreases. The idea of compensation runs through much scientific work including the more difficult conservation problems (a clay block remains the same volume when its shape changes: increase in thickness compensated for by decrease in length, etc.). As a field exercise this is a genuine bit of research, since the outcome is not known to pupils, teachers, nor to anyone else!

Apparatus summary

Groups of three are ideal for this.

Per group

- A half-meter rule and a caliper gauge 'diameter measurer' (see Example Card A and Appendix)
- Workcard A or B

  Choose the one according to the gauge you are using
- Example Cards B and C (optional)

Per pupil

- Worksheet (and something to press on)

Identify in advance bushes near the school which are suitable.

If it is impossible to take the pupils out to measure bushes, you could bring in branches cut from trees which have plenty of joints, or as a last resort use copies of drawings (which pupils can measure in mm instead of cm). Example Cards B and C may be used as drawings or projections.

Procedure summary

1 Refer to the Workcards, and go through the first couple of paragraphs. Introduce the word compensation. There is no 'right' answer to this exercise, it is a genuine investigation into a relationship between branch thickness and distance from ground.

2 Demonstrate how to use the caliper gauge or card gauge.

3 Check that all pupils know how to count up the number of joints.

4 Take the class out and point out suitable bushes; record observations on Worksheet.

5 Back in class, lead the discussion about the relationship, summarised at the end of the Workcard.

6 Pupils plot graphs on Worksheet.

7 For pupils, the important thing is that with compensation relationships the line slopes backwards.

Procedure details

1 Go through the first couple of paragraphs of the Workcards, emphasising the variables to be measured. Make it clear that as you go higher up a tree, the branches get thinner – as distance up increases, branch diameter decreases. 'One goes down as the other goes up.' This can be described as **compensation**.

Make the point that there is no 'right' answer to this exercise, it is a genuine investigation into a relationship between branch thickness and number of joints for the particular bushes around your school.

2 Demonstrate how to use the caliper gauge or card gauge.

3 Go over the picture of the bush on the Workcard or Example Cards, ensuring that all pupils are clear how to count up the number of joints between the branch they are measuring and the ground, or the main branch or trunk.

4 Lead the class out to an area of bushes already identified, and point out one or two suitable ones as examples. You will probably be kept quite busy answering questions such as 'do we count this as a joint?', and 'whereabouts exactly should we measure?'. Frankly, your answers are not very important, as long as they are consistent.

5 When everyone has sets of measurements on at least two bushes, return to the class, and lead the discussion about the relationship, summarised at the end of the Workcard. By now, many pupils will have the idea that in order to investigate a relationship, it is a good idea to draw a graph. Maybe someone can predict what direction the graph will go for this compensation, one up-one down, sort of relationship.

6 Now they can plot their graphs. They will have to make their own vertical scale, according to the thickest branch that they have measured. Points for the two or three different bushes can be plotted in the same space, using different colours.

7 Treatment of results: We found that the central section of the graphs from many bushes is actually a straight line (from the upper left to lower right), which struck us as being a rather odd relationship (*not* inverse proportionality,

but of the form: $ax + by = c$). For the pupils, the important thing is that this is a case of compensation. As the number of joints goes up thickness goes down. The line, whether straight or not, slopes backwards.

When measuring living things, there is a lot of random variation, so it is legitimate to draw a 'best fit' straight line along points nearly on a straight line.

There may be other interesting observations, such as if a branch has been cut, it tends to thicken, with the effect that the straight line curves to flat at the end.

Your name: ....

THINKING SCIENCE
ACTIVITY 9
WORKSHEET

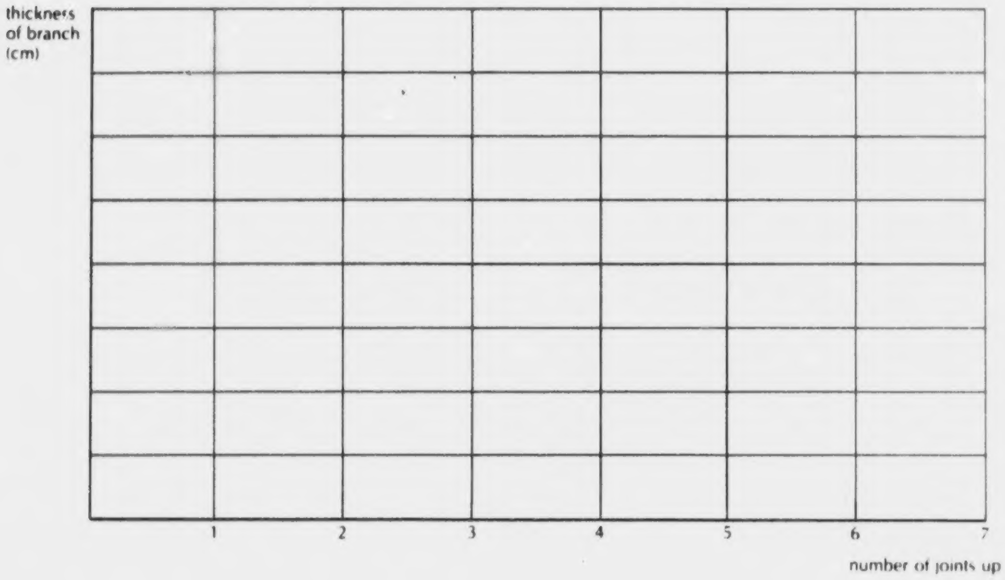
Activity 9: Worksheet
Trunks and twigs

Compensation

Record your results in these tables:

1st bush		2nd bush		3rd bush	
Number of joints up	Thickness (cm)	Number of joints up	Thickness (cm)	Number of joints up	Thickness (cm)
0		0		0	
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
6		6		6	
7		7		7	
8		8		8	

Plot graphs of the thickness of branches against numbers of joints up.



Activity 9: Workcard A Trunks and twigs

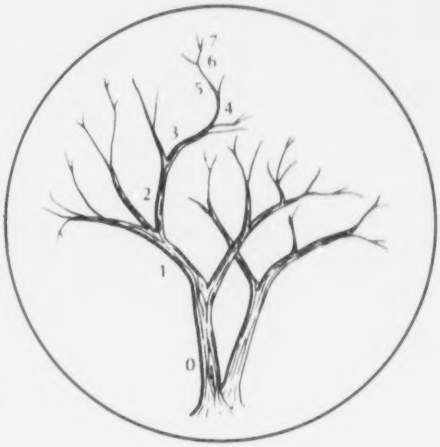
Compensation

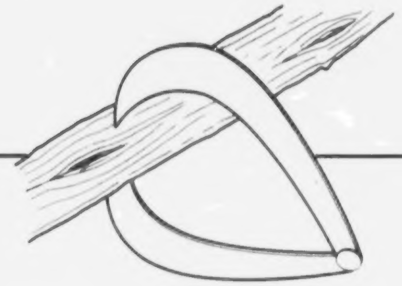
The higher up a tree you go, the thinner the branches become.

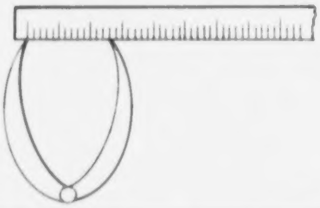
But what exactly is the relationship between:

- the thickness of a branch, and
- the number of times it has branched from the ground?

You can find out by measuring some bushes.







How to measure the thickness of a branch

Use a caliper gauge and a ruler.

Open the caliper until the branch just passes between its points. Measure the distance between the points.

If the branch is not really round, measure across the thinner direction.

How to count joints

Look at the picture of a bush above. Where the 0 is written, there are *no* joints between the branch and the ground.

Where the number 1 is written, there is one joint between the branch and the ground, and so on.

(If there is a tiny twig coming off a branch, do *not* count this as a joint.)

Activity 9: Workcard B Trunks and twigs

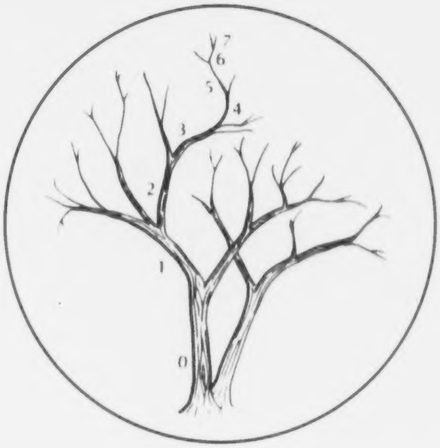
Compensation

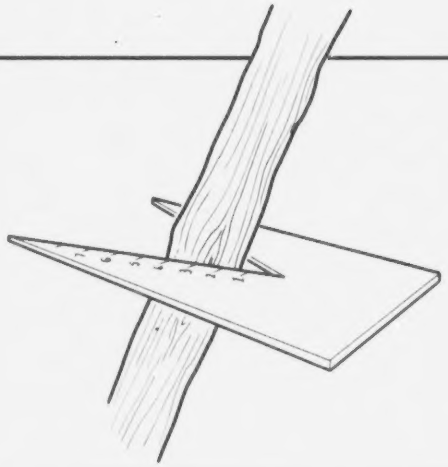
The higher up a tree you go, the thinner the branches become.

But what exactly is the relationship between:

- the thickness of a branch, and
- the number of times it has branched from the ground?

You can find out by measuring some bushes.





How to measure the thickness of a branch

You need to use the special gauge.

Push the gauge gently around the branch. Read the diameter from the mark that touches the branch.

If the branch is not really round, measure across the thinner direction.

How to count joints

Look at the picture of a bush above. Where the 0 is written, there are *no* joints between the branch and the ground.

Where the number 1 is written, there is one joint between the branch and the ground, and so on.

(If there is a tiny twig coming off a branch, do *not* count this as a joint.)

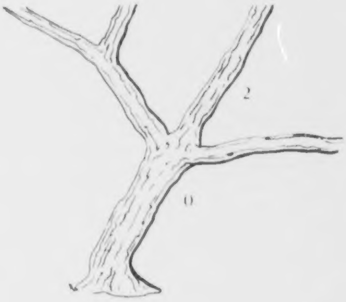
▶

What to do

1 Find a bush which has quite a lot of branching. Start with the trunk (or one of the trunks) coming from the ground. Measure its thickness, and write this next to the 0 in the table on the Worksheet.

2 Now follow that branch up, just past the first joint. Choose the larger of the two branches after the joint. Measure its thickness, and record it in the table next to the 1.

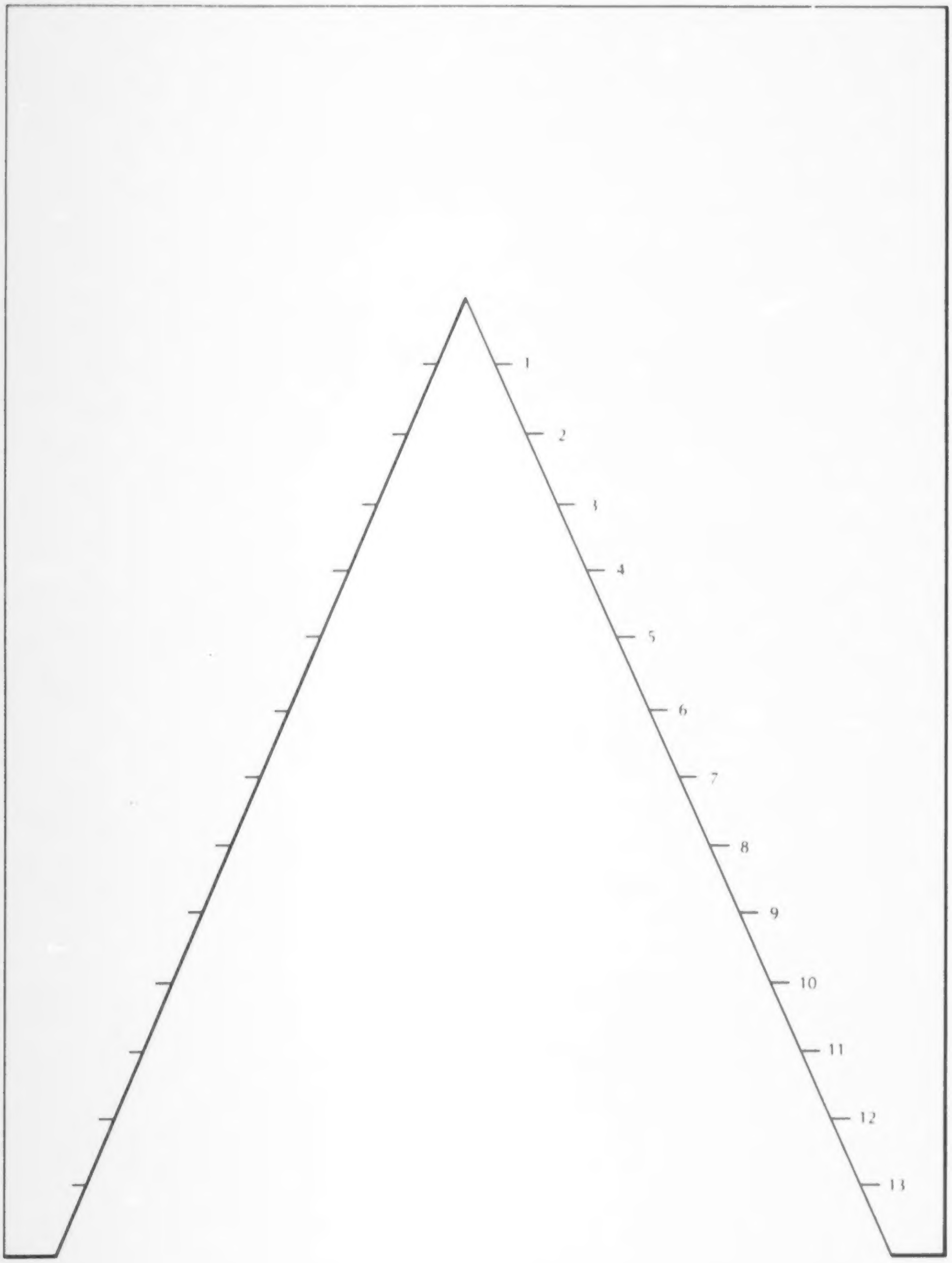
If two branches come off at once, like this, you cannot get a measurement at '1 joint up'. Go straight to '2 joints up'.



3 Carry on as far as you can go, until you cannot reach, or you reach the top of the bush, or you have gone beyond eight joints. Record all your results carefully in the tables on the Worksheet.

4 Do the same thing again with a different type of bush. If you have time, repeat again with a third species of bush. Use optional tree pictures 1 and 2.

Activity 9: Example Card A
Diameter gauge


1
2
3
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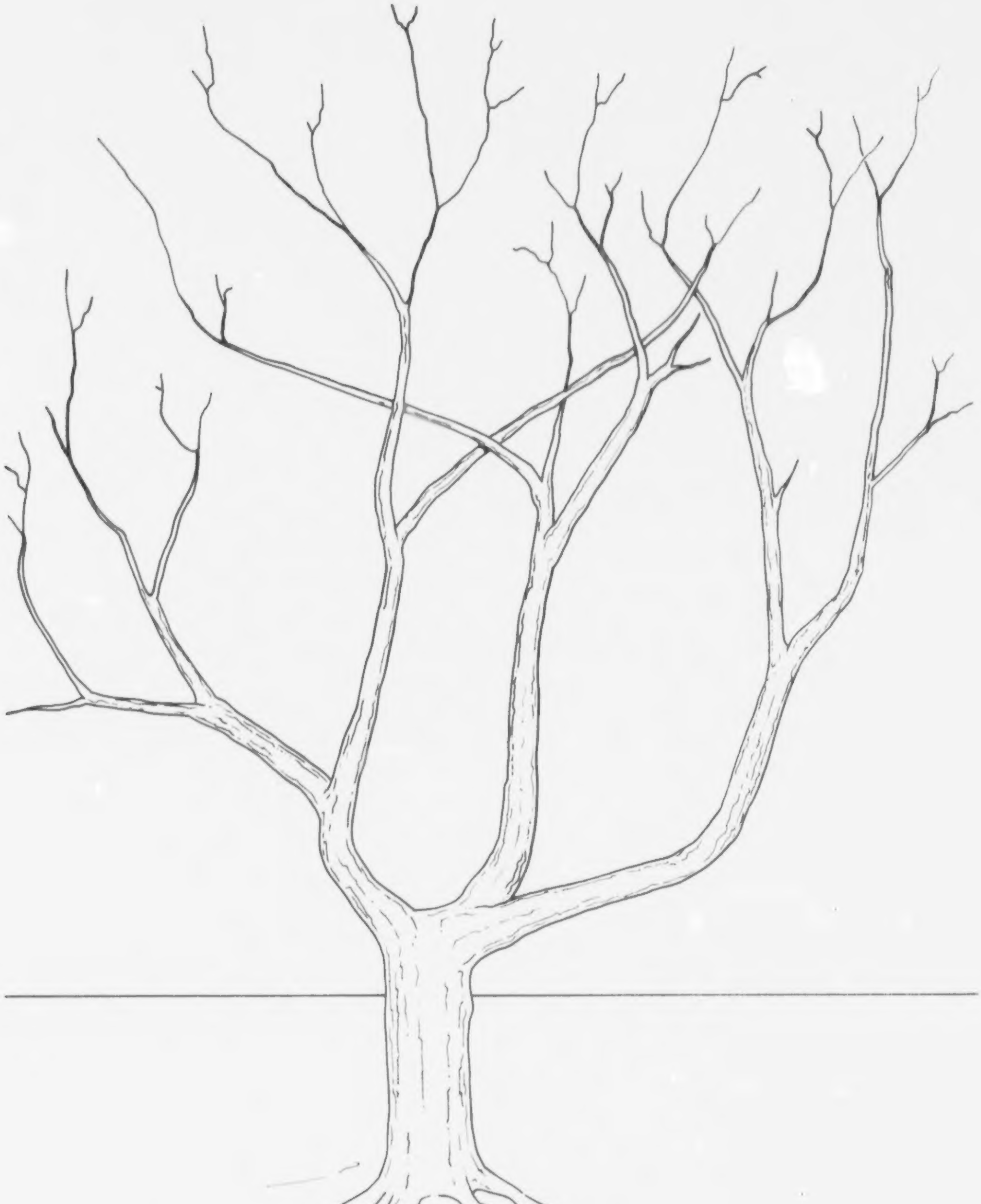
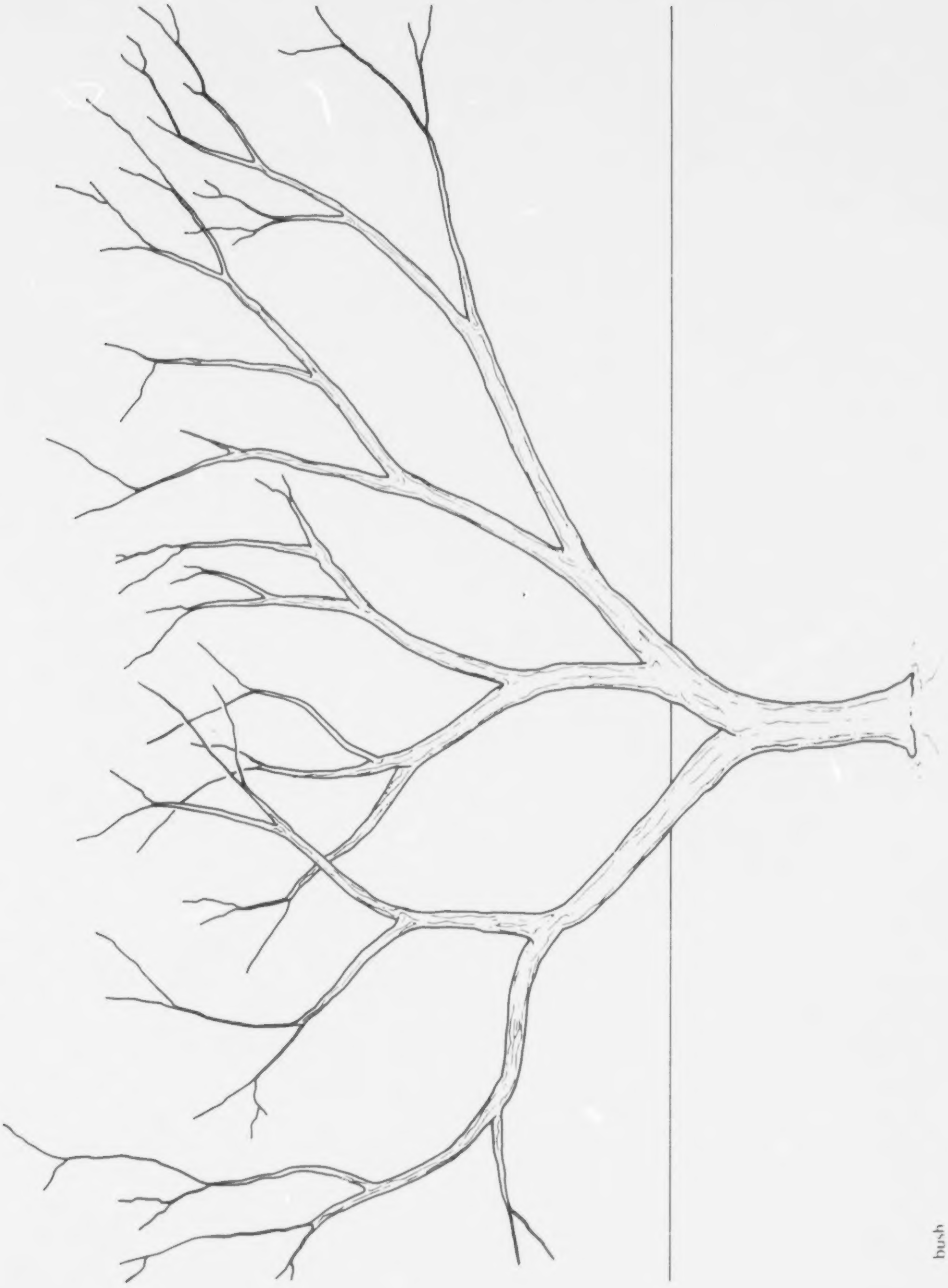
11
12
13

Activity 9: Example Card B
Optional tree picture 1



Activity 9: Example Card C
Optional tree picture 2



Activity 10: The balance beam

Compensation

Introduction

In this activity the compensation idea is treated quantitatively. We concentrate on just one side of the balance beam, where it can be seen that an increase in weight can be compensated for by a decrease in distance from the fulcrum. (Note that if both sides of the beam are considered, then the schema of equilibrium is involved. We deal with that later.)

Apparatus summary

Per group

- A piece of lath drilled to allow it to be hung with weights on either side
- Retort stand and clamp, with a nail as fulcrum
- Two S hooks, and two hangers and weights
- Workcard

Per pupil

- Worksheet

Procedure summary

1 Show the beam with 400 g hanging from hole 2 on one side. Pupils are to investigate how to make the beam balance with different weights and distances on the other side. They complete the first table on the Worksheet.

2 Pupils work through 2nd and 3rd sections of the Worksheet. Discuss the general rule (after part 2 of the Worksheet) with the whole class.

3 In part 3, they try 100 g weight (hole 6) and hole 1 (600 g), then *predict* what weight would be needed in hole 3 (200 g) and what hole you would put a 150 g weight in (4).

The 'fixed' weight and distance is not important – the problem being what different ways it can be balanced.

4 Workcard problems can be done by individuals or groups, in class or as homework.

Procedure details

1 Show the beam with 400 g hanging from hole 2 on one side (say, their left). Explain to pupils that they are going to investigate how to make the beam balance with different weights at different distances from the centre on the right hand side. Let them complete the first table on the Worksheet, which refers to the right hand side only. The output variable is simply 'balance' – values are: it balances, or it does not ('yes' or 'no').

2 Pupils should now be able to work through the 2nd and 3rd sections of the Worksheet with more or less assistance from you. You might discuss the general rule (after part 2 of the Worksheet) with the whole class.

3 In part 3, they are only supposed actually to try out the 100 g weight (hole 6) and hole 1 (600 g), then *predict* what weight would be needed in hole 3 (200 g) and what hole you would put a 150 g weight in (hole 4). For each, they ask themselves 'what value do I need to make the product the same?' (in each case, 600).

What you will accept and encourage as 'a good answer' to the general rule depends on the age and ability of the student. The top level answer could be something like 'if the product of weight (mass) and distance remains the same, then the effect remains the same'. You would be lucky to get such an answer from a 3rd year undergraduate physicist. Any variation on such an answer, which seems to convey that meaning, is good. But also, 'If you double the distance out, you must halve the weight' is a very good answer at a lower level.

The value and distance of the weight on the left hand side is not important – it is taken as a fixed value each time, the problem being what different ways this fixed value can be balanced. This is emphasised in part 4, where the 'fixed' weight (shown on the right of the diagrams) is not even known.

4 The Workcard problems give a series of 'though experiments'. Whether you get individuals or groups to work on these; whether you lead the class through them or give them for homework, will depend on their ability and your preferred style. Question 3 is for the most able pupils. It leads to the idea of one variable being proportional to the square of another.

Your name: ....

Activity 10: Worksheet
The balance beam

Compensation

A beam can be made to BALANCE
by using different WEIGHTS
at different DISTANCES from the centre

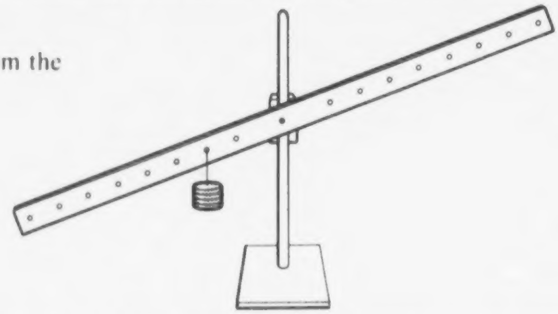
1

Complete this table to describe the variables involved:

Input		Output	
variable	values	variable	values
....	100 to 800 g	balance	....
distance from centre	....		

2

Put a 400 g weight two holes from the centre.



Try to balance the beam with different weights at different distances on the other side.

Write in all of the combinations of weight and distance that make the beam balance.

In the last column, multiply the weight by the distance.

Weight grams	Distance (hole)	Weight × distance

What do you notice about the product of weight × distance?

....

What is the relationship between weights and distances in the table?

....

Your name: ....

If you have a smaller weight, you can **compensate** for it by hanging it further out.

If you can only hang the weight a short distance from the centre, you can **compensate** for this by using a heavy weight.

3

Hang 300 g at hole 2 on one side.

Investigate what weights at what distances on the other side you need to make the beam balance:

Weight (grams)	Distance (hole)	Weight × Distance
100 g	....	....
....	1	....

a What hole must you put a 100 g weight in to make it balance?

b What weight do you need in hole 1 to make it balance?

Now, *without trying it*, can you work out:

c What weight you would need in hole 2 to make it balance? ....
(*Hint* What must you times 2 by to get 600?)

d In what hole must you hang a 150 g weight for it to balance? ....

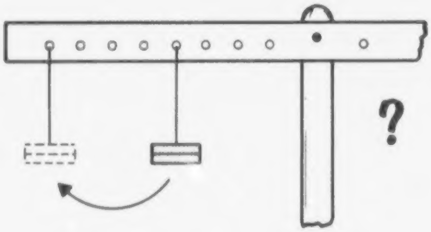
Try to write a *general rule* for the relationship between the different weights and distances which have the same effect:

....

....

4

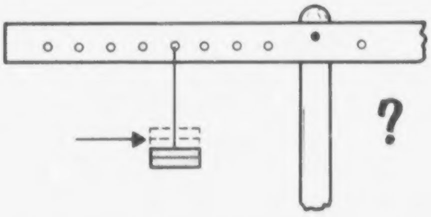
Suppose you have 200 g hanging in hole 4, balanced by a weight on the other side.



If you move the weight out to hole 8, how should you change the weight to compensate?

....

Starting again with the 200 g in hole 4, you now double the weight, to 400 g. To which hole must you move it so that the beam balances?



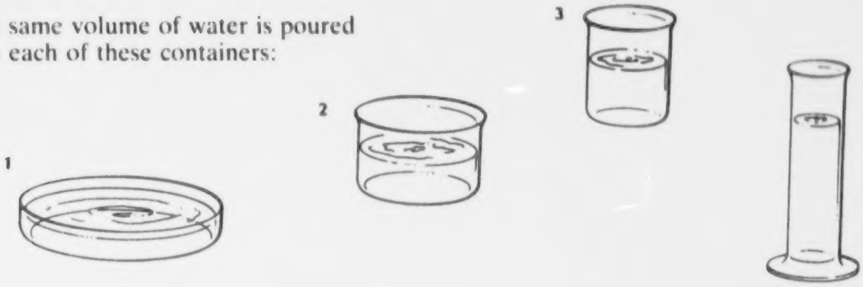
....

Activity 10: Workcard The balance beam

Compensation

Problems

1 The same volume of water is poured into each of these containers:

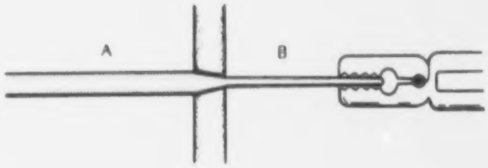


Someone then measures the *surface area* of the water in each container, and the *depth* of the water in each container. Here are her results

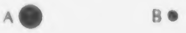
Container	Surface area	Depth
1	100 cm^2	5 cm
2	50 cm^2	10 cm
3	20 cm^2	25 cm

- a What happens to the depth of the liquid as the surface area decreases?
- b For each container, multiply the area by the depth. What do you notice about the area × depth products (the volume)?
- c Write a general rule which says what happens to the depth of the liquid if you change the surface area. Try to use the word 'compensate'.
- d If the same volume of liquid is poured into container 4, its surface area is 10 cm^2. How deep is it?

2 A thick piece of wire can be made into a thin piece of wire if it is pulled through a 'die' like this:



The ends of the wire (cross-sectional area) look like this:



- a What has happened to the cross-sectional area of A to make it into B?
- b What do you think happens to the length of the new wire B? Will B be shorter than the old wire A, the same length as A, or longer than A?

▶

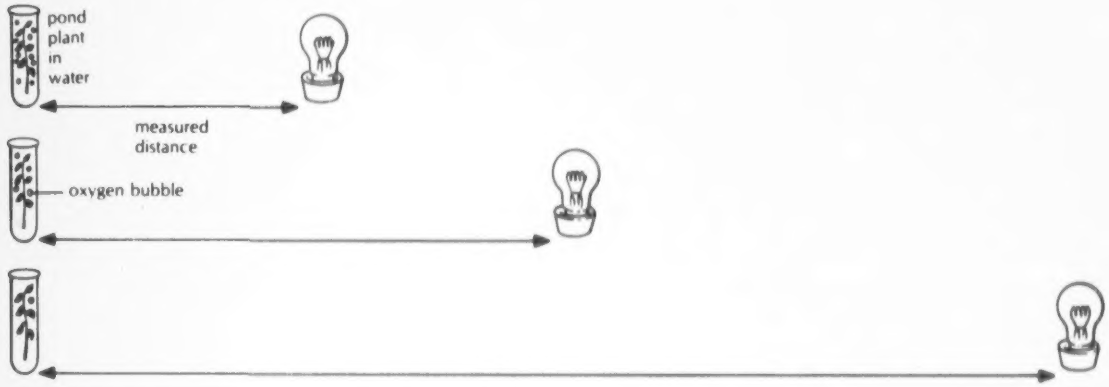
c Write a rule which says what happens to length if you decrease the cross section of a wire by drawing it through a die. Use the word *compensate*.

d If the cross-sectional area of the wire is *halved* as it is pulled through the die, what happens to its length?

e A wire is 1 metre long and has a cross-sectional area of 9 cm^2. After it is pulled through a die, it is 3 metres long. What is its cross-sectional area?

3 A pond plant will produce bubbles of oxygen in water when a bright light is shone on it.

The pictures show how many bubbles are given off in ten minutes when a lamp is put at different distances from the plant.



a Make a table like the one below. Measure the distance of the lamp from the plant in each picture, and put your results in the first column of your table.

Measured distance	Distance squared	Number of bubbles	Bubbles × distance

The light reaching the plant gets less, proportionally to *the square* of the distance of the lamp. This means that if you double the distance of the lamp, you reduce the amount of light by ½ × ½ (=¼).

b So, find the square of the distance (multiply it by itself), and write this in the second column of your table.

c From the pictures, count the bubbles given off in ten minutes, and write the answer in the third column. Now multiply the number of bubbles of oxygen by the squared distance of the lamp from the plant, and put your answer in the last column of the table. What do you notice?

d What is the relation between the amount of light that falls on the plant, and the number of bubbles of oxygen that are given off?

e If you were to use a dimmer lamp, what could you do to make it produce the same amount of oxygen?

f What word would you use to describe this?

Activity 11: Current, length and thickness

Compensation

Introduction

This activity presents compensation relationships in the context of the effect of the length and thickness of a wire on the current that passes through it. (The word resistance is not actually needed.) The relationship between wire length and current demonstrates inverse proportionality, expressed in concrete terms as 'when the length doubles, the current halves' – a special case of compensation. Students also find practically, and consolidate with problems, that a short thick wire allows as much current as a long thin one – compensation again.

Apparatus summary

For demonstration

- 12 V lamp and power pack
- 1.6 m of 30 swg constantan wire (copper-nickel alloy)

Per group

- Power pack, ammeter, connecting wires, 1.6 m lengths of constantan wire, 30 swg and 36swg (If your resistance wire is different, you will have to check the experiments and possibly alter the recommended voltages and lengths.)
  Have some 28 swg in reserve for groups who finish quickly.

Per pupil

- Worksheet
- Workcard

Procedure summary

1 Make a circuit with the power pack and a bulb. Emphasise the idea of electric current flowing around the circuit.

2 Now include the resistance wire in the circuit. Show that the longer the wire, the dimmer the bulb (i.e. the less the current). The variables are length of wire and current. Introduce the ammeter to measure current.

3 Pupils follow Worksheet activities. Help with circuits and problems, and encourage small group discussions.

4 They may conclude (end of section 3): 'The longer the wire, the less current'; 'If you double the length of the wire, you halve the current that passes'; or 'By whatever proportion you increase the length of the wire, so the current is reduced by the same proportion.' Try to crystalise this thinking as **compensation** – one goes up as the other goes down. In this case, current is inversely proportional to length.

5 Further work includes using thicker wire or plotting a graph.

6 **The Workcard problems can be done in class or as** homework.

Procedure details

If pupils are already familiar with ammeters, you can shorten procedures 1 and 2 to a brief introduction to the investigation.

1 Show the power pack, from which we can get safe, small amounts of electricity; wires for making connections; and the bulb in a holder. Connect one wire from the power pack to the bulb holder, then another from the other side of the bulb holder. When you complete the circuit back to the other terminal of the power pack, the bulb lights, when you break it, it goes out. Emphasise the idea of an electric current flowing around the circuit.

2 Now show the piece of constantan wire. Make the circuit again, but this time with the length of wire in it. Hold one end of the wire with a crocodile clip, and put the other crocodile clip close to the first. The bulb lights as before. Electric current can pass through the wire. Now move the second clip further away from the first, so the length of wire that the current has to pass through becomes longer. The bulb becomes dimmer – because there is less current passing through it. Lead to the conclusion that the longer the wire, the harder it is for the current to flow.

The variables here are length of wire and current. Pupils are going to investigate the relationship between these variables – but first we need a method of measuring current. You could discuss the problems of using bulb brightness – it doesn't have a definite scale, and it would be difficult for two people to agree that this bulb was exactly twice as bright as that one.

Introduce the ammeter as a meter which measures the current. The unit of current is the amp. According to the type of ammeter that you have, explain how to read the scale. Put the ammeter into the curcuit and then show that as the bulb gets dimmer, the ammeter reading is less.

3 Refer to the Worksheets and apparatus. The Worksheet should lead them through the rest of the activity, but you will be kept busy helping with circuits and problems, and encouraging small group discussions on interpreting results. In particular:

- some pupils will need help in reading the ammeter correctly.
- make sure they measure 160 cm, not 160 mm.
- watch out for loops in the long wires causing short circuits and spurious results.
- some pupils may not be happy with the approximations that must be made – figures will rarely come out neatly as 'half the length, twice the current'.

4 Possible answers to the 'summarise' question, at the end of section 3, are (in increasing order of sophistication):

> 'The longer the wire, the less the current.'
>
> 'If you double the length of the wire, you always halve the current that passes.'
>
> 'By whatever proportion you increase the length of the wire, so the current is reduced by the same proportion.'

In discussion with the class or small groups try to crystallise this thinking as **compensation** – one goes up as the other goes down. In this case, there is an 'upside down' (inverse) proportionality between length and current.

5 Pupils who finish the Worksheet in good time may be given a thicker piece of wire (e.g. 28 swg), or could be asked to plot a graph of current against length. The curve obtained is characteristic of inverse proportional relationships, but interpretation of this (and the need to plot 1/A against length to get a straight line) will probably be beyond all but a very few.

6 There is a sheet of (rather difficult) **Workcard** problems which can be done in class or as homework. Here are some suggestions about answers.

Workcard Answers

1 Thicker wire.
2 After the 'fair' test idea again, looking for the choice of two wires of the same length.
3 They will almost certainly need reminding of the phrase 'inversely proportional'.
4 We are after 'shorten the wire', and 'use thicker wire'. Some may say 'use copper wire', which is another good answer. If they do, push for the third way.
6a Current doubles
b Four times the current
c (i) 1.6 A (ii) 0.4 A (iii) 0.6 A (iv) 3.2 A
7 'Fair' test again – use same length of both wires.

Your name: ....

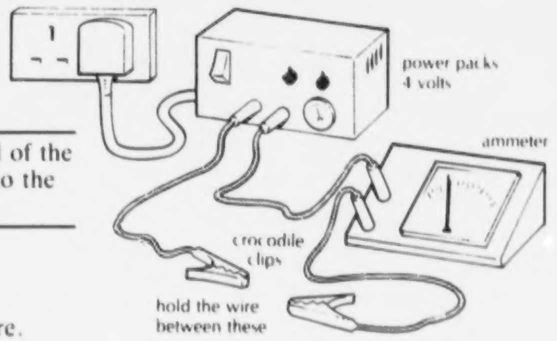
Activity 11: Worksheet Current, length and thickness

Compensation

Your are going to investigate the relationship between the length of a wire and the current that passes through it.

1 *Setting up*

Set up a circuit like this:



Remember that the red terminal of the power pack must be connected to the red terminal of the ammeter.

a Set the power pack to 4 V

b Measure 160 cm of special wire. Clip one of the crocodile clips on each end.

Make sure that there are no loops in the wire which could 'short circuit' it.

If the ammeter needle moves to the left, it is wrongly connected. Check the circuit again.

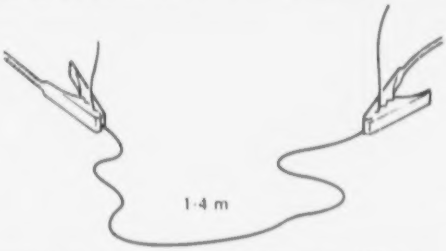
c Read the ammeter. Write the current under '160 cm' in the table.

Length of wire (cm)	160	140	120	100	80	70	60	50	40
Current (amps)									

2 *Different lengths*

a Leave one crocodile clip on the wire. Move the other one so that they are just 140 cm apart.

b Read the ammeter and write the current under '140 cm' in the table.



c Use the same method to find the current that passes through 120 cm, 100 cm, and so on, down to 40 cm. *Do not go below* 40 cm. Complete the table.

▶

Your name: ....

3 *The relationship*

From your table, complete these sentences.

a When the length of the wire is *halved* from 160 cm to 80 cm, the current goes from .... A to .... A.

b When the length of the wire is *halved* from 140 cm to 70 cm, the current goes from .... A to .... A.

c When the length of the wire is *halved* from 120 cm to . . . . cm, the current goes from .... A to .... A.

Make up one more of your own.

d When the length of the wire is *halved* from . . . . cm to . . . . cm, the current goes from .... A to .... A.

e In general, what happens to the current (approximately) when you halve the length of wire? ....
....

f What happens to the current when you divide the length of wire by 3? (Compare 150 cm and 50 cm) ....
....

g *Summarise* the relationship between the length of wire and the current that passes through it:

....

....

4 *Change the thickness*

Get a thinner piece of wire, and repeat the experiment. Put your results in this table:

Length of wire (cm)	160	140	120	100	80	70	60	50	40
Current (amps)									

Is there the same relationship between length and current as there was with the thicker wire? YES/NO

Why do you think this is so?

....

....

Activity 11: Workcard Current, length and thickness

Compensation

Problems

1 Which allows current to pass through more easily, thin wire or thicker wire?

2 If you wanted to prove from the results of your experiment that your answer to question 1 was correct, which results would you choose? Why?

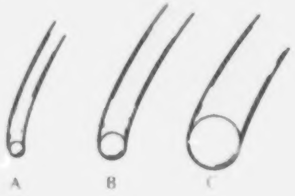
3 By whatever proportion you shorten the wire, so the current goes up by the same proportion. If you cut the wire to ¼ of its original length, the current goes up four times. (Compare the current at 160 cm and at 40 cm.) Does this mean that current is *proportional to* the length of wire? If not, what *is* the relationship?

4 You have a long thin iron wire running from a light switch to a light. The light is rather dim. Think of at least *two* ways you could change the wire to make the lamp brighter.

5 Use the word *compensate* or *compensation* in a sentence about the effect of length and thickness of a wire on the current that can pass through it.

6 A scientist measures the thickness of three wires, A, B, and C. Then she works out the cross-sectional area of each. These are her results:

Wire	c-s area (mm^2)
A	0.15
B	0.30
C	0.60



Now she uses the same sort of experiment that you did, to measure the current that passes through different lengths of the three wires. Her results are summarised in this table:

Length (cm)	Current (amps)		
	wire A	wire B	wire C
160	0.2	0.4	0.8
80	0.4	0.8	1.6
40	0.8	1.6	3.2

Use these results to answer the following questions:

a If you double the cross-sectional area of a piece of wire, what happens to the current that passes through it?

b What is the effect on the amount of current that can pass, if the cross-sectional area of the wire is increased four times?

c Under the same conditions, what current would you expect to pass through these wires:

- i) 20 cm of wire A
- ii) 320 cm of wire C
- iii) 120 cm of wire B
- iv) 80 cm of a wire D, which has a cross-sectional area of 1.2 mm^2?

7 If you had two different wires X and Y, with cross-sectional areas 0.2 mm^2 and 0.6 mm^2, how would you try to show that three times as much current can pass through Y as through X? ■

Activity 12: Volts, amps and watts

Introduction

This is the last of the compensation activities. One rather simple new electrical relationship is introduced, and then the whole idea of compensation is reviewed.

Apparatus summary

Per group

- *Either* 3 × 1.5 V cells, 1 A ammeter, bulb holder and e.g. 1.25 V, 2.5 V and 3.5 V or 4.5 V torch bulbs
- *Or* selection of car bulbs and holder, power pack, 5 A ammeter

Some schools use both sorts of apparatus, with pupils either changing, or comparing notes.

Per pupil

- Workcard A
- Workcard B

Procedure summary

1 Recap the last activity. Introduce the unit 'watts', refer to light bulbs, amplifiers, kettles etc. 'Watts' as a measure of the **power** of an appliance.

2 First few lines of Workcard A: power calculated by multiplying the voltage times the current.

3 With torch bulbs the question is 'What is the power of the torch bulbs', and with car bulbs it is 'How does the actual power output compare with the rating?'.

4 Give each group one cell (for the torch bulb version) and one bulb at a time. After one measurement you can give out another cell and the next bulb.

5 Pupils establish practically: voltage × current = power (watts). With problems on **Workcard B**, they find equivalent sets of voltage and current that give the same power.

6 Consolidate all the work on compensation – the one-sided balance beam; the resistance of a longer wire can be compensated for by making it thicker; to get the same power from a smaller voltage, you need a larger current. Add other examples.

7 If possible, formalise the argument with equations such as:

weight × distance = turning force
voltage × current = power
length/thickness = constant

Procedure details

1 Recall the last activity, and the idea of compensation between length and thickness of wire. The relationship is quantitative and reliable. If wire A is three times as thick as wire B, then for the same current to pass, wire A must be three times as long as B. This activity is another exploration of compensation. Where have students come across the unit 'watts'? – light bulbs, amplifiers ('100 watts per channel'), kettles, fan heaters, etc. 'Watts' are a measure of the **power** of an appliance. (There is no need to define power formally, it is acceptable in its common usage.)

2 Go through the first few lines of Workcard A: the power of an electrical appliance can be calculated by multiplying the voltage at which it runs times the current that passes through it. Current, a word used in the last activity, is a measure of the flow of electricity. Voltage will probably be familiar as a word, as in the voltage of 'batteries', the voltage of a car battery, and mains voltage. There is no need (and no point in trying) to get across a concept of what voltage is. The idea of something like the 'strength' or 'pressure' of electricity that you can get from a particular source is enough.

3 The problems being investigated in the two pupil versions are slightly different. With torch bulbs it is 'What is the power of the torch bulbs?' – a matter of taking the voltage as the number of cells (×1.5 V), measuring the current, and multiplying them together in each case. Car bulbs generally have their theoretical wattage clearly marked on them, so the problem is 'How does the actual power output, in watts, compare with the rating?'. It is always lower, because the rating is a maximum power, and there is a margin of safety to prolong the life of the bulb.

4 It is probably best to give each group just one cell (for the torch bulb version) to start with, and one bulb at a time. When they finish the first measurement and bring back the bulb you can give out another cell and the next bulb. This reduces the chance of three cells being put across a one cell bulb, or 12 V across a 6 V bulb.

5 The purpose of the activity is to establish practically:

voltage × current (amps) = power (watts)

Compensation comes in when pupils use that relationship to find equivalent sets of voltage and current that will give the same power: for instance 12 V × 0.5 A, 6 V × 1.0 A, 240 V × 0.025 A, are all equivalent to a power of 6 W. Thus the problems on Workcard B are much more than time-fill or consolidation, they are essential to this activity. Pupils may do these individually, in pairs, or in threes, but if they work in groups try to ensure that all participate, rather than one doing the work and the others writing the answers! You will need to go around and help as they work. They could be done as homework once you have established that they have the general idea.

6 Try to reserve five or ten minutes at the end of the lesson to consolidate all the work on compensation. Remind pupils of the three compensation activities. In the one sided balance beam, a smaller weight could be compensated for by putting it further out; for controlling the current, a longer wire could be compensated for by making it thicker; and to get the same power from a smaller voltage, you need a larger current. Make up some more problems, or ask pupils to think of other examples of compensation. They may come up with examples such as receiving 'compensation' for loss of a job, or a farmer's need to compensate for poor soil by putting fewer animals to graze on it. These are good examples of qualitative compensation, but should be compared with the quantitative compensations we have been dealing with. For any given change in one variable, we can calculate precisely the change there must be in the other variable to keep something the same.

7 If things are really going well, you could formalise the argument with equations such as:

weight × distance = turning force
voltage × current = power

For the resistance of a wire, the form is a little different:

$$\frac{\text{length}}{\text{thickness}} = \text{constant}$$

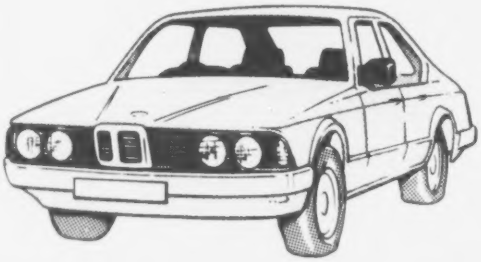
Workcard B Answers

1 e.g. 12 V, 1 A; 24 V, 0.5 A; 6 V, 2 A; etc.
2 a 0.25 A c 1 A d 1.5 A e 5 A
3 a and d
4a 'Easyglide' half as powerful as 'Smoothall'.
4b 'Flattener' takes twice the current of 'Smoothhall'.
5 0.6 V
6 c
7 a 3 W b 88 W c 1100 W d 330 W e 100 W
8 a 3 A b 2 A c 4 A d 0.5 A e 1A

Activity 12: Workcard A (cars) Volts, amps and watts

Compensation

A WATT is a measure of POWER
VOLTS times AMPS equal WATTS
V × A = W



Most cars have 12 volt batteries. (Some used to have 6 volt batteries.)

If you have to replace a bulb, you must choose the right bulb.

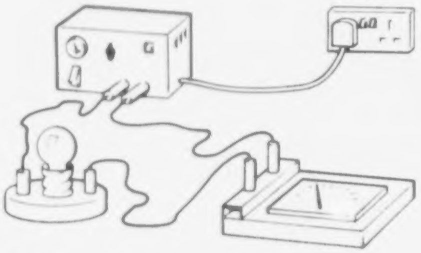
a It has to be the right *voltage*.
(If you put a 6 V bulb in a car with a 12 V battery, the bulb will blow.)

Never connect a bulb to a higher voltage than it is meant for!

b It has to be the right *power*.
A headlight may need a 36 W bulb. A sidelight only needs a 5 W bulb.

Measuring the power of a bulb

1 To find the power of a car bulb, you need to measure:



- the voltage across it, and
- the current that passes through it.

Set up the circuit like this. It has a power supply (set to 6 V), a bulb in a holder, and an ammeter.

Start with a 6 V sidelight bulb (marked '5W')

Make a table in your notebook, or on paper, like this:

Bulb rating		Voltage (volts)	Current (amps)	Actual power volts × amps
volts	watts			
6	5			

2 Switch on the power. Observe how bright the bulb is. Read the current. Complete the first line of your table.

▶

3 Change the bulb for a different 6 V bulb. Read the current, and complete another line of the table.

Repeat with other 6 V bulbs, if possible.

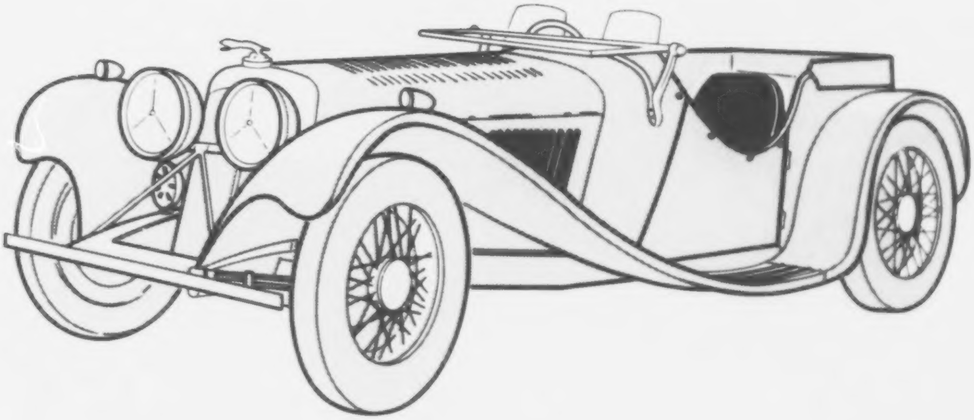
4 Return the 6 V bulbs to your teacher. Get some 12 V bulbs.

Change the power pack to 12 V.

Repeat the experiment, filling in a line of the table for each bulb that you use.

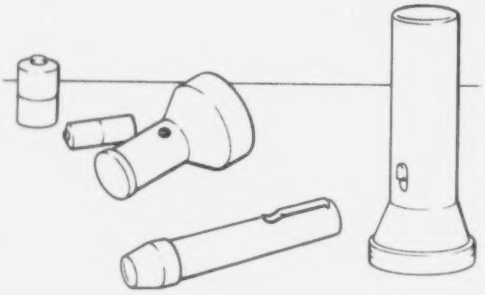
5 Compare the actual power output of each bulb with the power rating written on it.

What do you notice? How can you explain this?



Activity 12: Workcard A (torch) **Compensation**
Volts, amps and watts

A WATT is a measure of POWER
VOLTS times AMPS equal WATTS
$V \times A = W$



Some torches take one cell, some take two cells, and some take three cells.

One cell is 1.5 volts.

Think what would be the voltage in
  a one cell torch,
  a two cell torch,
  a three cell torch?

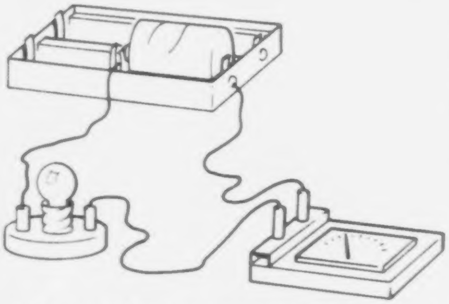
If you have to replace a torch bulb, you must choose the right bulb. It has to be the right *voltage*, for the number of cells in the torch.

If you put a 3 V bulb in a torch with three cells, the bulb will blow. 4.5 V is too much for a 3 V bulb.

Never connect a bulb to a higher voltage than it is meant for!

Measuring the power of a bulb

1 To find the power of a torch bulb, you need to measure:



- the voltage across it, and
- the current that passes through it.

Set up a circuit like this. It has *one* cell, a bulb in a holder, and an ammeter.

Start with a 1.25 V bulb.

Make a table in your notebook, or on paper, like this:

Bulb	Number of cells	Voltage (volts)	Current (amps)	Power output volts × amps
1.25 V	1			watts

►

2 Switch on the power. Observe how bright the bulb is.
Read the current. Complete the first line of your table.

Switch off the current after you have made the reading.
Do not waste the battery.

3 Change the bulb for a different voltage bulb.
If you use a 2.5 V bulb, you will need a second cell.

Read the current, and complete another line of the table.

4 Repeat with other bulbs.
With a 4.5 V bulb you will need three cells.

Complete a line of the table for each bulb that you use.

5 Compare the bulbs.
Now make a table like this:

Bulb (voltage)	Power (watts)	Brightness

In the first two columns, list the bulbs in order of their power (with the lowest power first).

Connect each bulb in turn to **just one** cell (1.5 V). Note how bright each one is.

In the last column write 'brightest' next to the brightest bulb. Write 'dimmest' next to the dimmest one.

What is the relationship between power and brightness, when all are connected to the same voltage?

Can you explain this?

Activity 12: Workcard B
Volts, amps and watts

Compensation

Problems

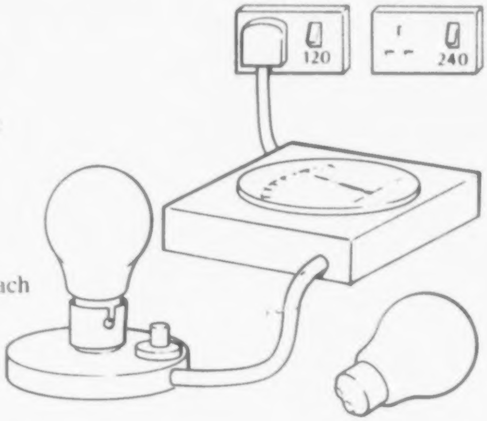
> 'If you double the voltage,
> you have to halve the current
> to keep the power the same.'

1 One combination of voltage and current that would give a power output of 12 W is 3 V, 4 A. Find three other combinations of voltage and current that would give a power output of 12 W.

2 A bulb of a certain wattage (power) takes 0.5 amp current at 120 volts.

a To get the same wattage, what current would a bulb have to take at 240 V?

b How did you work that out?



Still to get the same wattage, what current would be taken by bulbs at each of the following voltages:

c 60 V

d 40 V

e 12 V

3 Which *two* bulbs in the following list take the same current as each other?

a 6 V, 12 W

b 6 V, 24 W

c 6 V, 36 W

d 12 V, 24 W

e 12 V, 36 W

▶

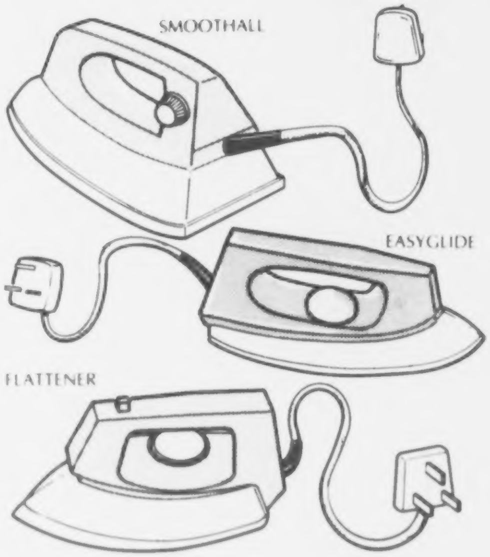
4 The 'Smoothall' electric iron is designed to give a certain power output at 220 V.

The 'Easyglide' iron takes the same current as the 'Smoothall', but at 110 V.

The 'Flattener' iron has the same power output as the 'Smoothall', but it is designed to run at 110 V.

a What is the ratio of the *power* output of the 'Easyglide' to that of the 'Smoothall'? Is the 'Easyglide' twice as powerful, half as powerful, the same, or what?

b What is the ratio of the *current* taken by the 'Flattener' to the current taken by the 'Smoothall'?



5 Bulb A takes 0.2 A current at 240 V. What current will bulb B take at 80 V if it is to give the same power?

6 Which *one* of the following bulbs does *not* have the same power (wattage) as the others?

a 6 V, takes 2.0 A
b 12 V, takes 1.0 A
c 24 V, takes 1.0 A
d 24 V, takes 0.5 A
e 36 V, takes 0.33 A

►

Power

The power (in watts) is given by
the voltage times the current
V × A = W

7 What is the power output of each of these devices?

a Lamp bulb : 3 V, 1.0 A:

b Lamp bulb : 220 V, 0.4 A:

c Fan heater : 220 V, 5.0 A:

d Electric drill: 220 V, 1.5 A:

e Amplifier : 25 V, 4.0 A:

8 What current would be taken by each of the following bulbs?

a 36 W, 12 V

b 24 W, 12 V

c 24 W, 6 V

d 3 W, 1.5 V

e 1.5 W, 1.5 V

Activity 13: Spinning coins

Introduction

This is the the first activity which deals with probability. Children often have an intuitive notion of 'chance' which tells them that there is an equal chance of a coin coming down heads or tails. This activity explores that notion, and starts to quantify it.

Apparatus summary

Per pupil (or group)

- A coin and a calculator
- Worksheet
- Example Card

Procedure summary

1 **Refer to the** Worksheets and practice use of the words **chance** and **probability** in different contexts. The variable when you spin a coin is the side which is up when it falls; its values are heads or tails. A coin is symmetrical in shape, so can be expected to fall on either side with equal frequency.

2 Each group spins their coin 50 times and records results in table A – the raw data for analysis in the rest of the lesson.

3 Then they count **runs**, complete table B, and add their results to the class results on the **Example Card**. Now they answer the questions on page 2 of the Worksheet.

4 For the third part, about proportions, life is easier if calculators are available. For each proportion calculated, a point is added to the graph and joined to the one before with a straight line.

The important point is the tendency of the line to approach 50 per cent.

Procedure details

1 This is a long activity to get into one double period. **Refer to the** Worksheets, explaining that they are going to investigate **chance**, or **probability**. Use the words in a number of different contexts, and ask questions to ensure that everyone has focused on the topic of the lesson. In particular:

- what is the variable involved when you spin a coin? (the side up when it falls)
- what are its values? (heads or tails).

Is the shape of a coin **symmetrical**? A coin is symmetrical in shape (if not with respect to the pictures on either side) and it is the shape that is important in determining the way the coin falls. (But some foreign coins, notably the Italian 100 lire piece, have heavier embossing on one side than the other – we had trouble with them in the trials.)

2 The first activity is just the collection of data: each group (or individual) spins their coin 50 times and records results in table A. This provides the raw data for analysis in the rest of the activity.

3 As each group completes 50 spins, they can go straight on to the second activity, counting the runs. Some will need help with this, especially in understanding that any run of tails counts as 1 run of no heads.

When they have completed table B, they should add their results to the class results on the Example Card. Watch this to make sure that the addition is correct. Having done this, they can answer the questions on page 2 of the Worksheet, which will form a basis for class or small group discussion.

4 The third part, about proportions, is not conceptually difficult but the calculations can be tedious. Life is much easier if there is a calculator avialable to each group, or even to each individual, since this activity could be done by each pupil working on her or his own original results (table A). For each proportion calculated, a point is added to the graph and joined to the one before with a straight line.

The important thing is the tendency of the line to approach 50 per cent. Even if only one or two graphs are completed, try to make sure that the whole class sees them and appreciates that once one has enough throws, the chance of a head coming up really does approach 1 in 2.

Your name: ....

THINKING SCIENCE
ACTIVITY 13
WORKSHEET

Activity 13: Worksheet Spinning coins

Probability

1 Heads and tails

When you spin a coin, how likely is it that you will get a long run of heads?

a Spin the coin once. In table A, next to the '1', write H if it comes down heads and T if it comes down tails.

b To see a pattern, you will have to spin the coin a lot of times. Spin it *50 times*, and fill in the table with Hs and Ts for heads and tails.

Table A

Spin number	H or T
1	....
2	....
3	....
4	....
5	....
6	....
7	....
8	....
9	....
10	....
11	....
12	....
13	....
14	....
15	....
16	....
17	....
18	....
19	....
20	....
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22	....
23	....
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30	....
31	....
32	....
33	....
34	....
35	....
36	....
37	....
38	....
39	....
40	....
41	....
42	....
43	....
44	....
45	....
46	....
47	....
48	....
49	....
50	....

2 Frequency of runs

You need to count the *runs* of heads. A 'Run' of heads is the number you get in a row, without a tail. So:

.... THHT ....would be a run of two heads
.... THHHT ....would be a run of three heads
.... THT ....would be a run of one head.

The **frequency** of runs of two heads is the number of runs of two heads you got in 50 throws.

a Go through all of the data in table A, and count the frequency of runs of one head, the frequency of runs of two heads, and so on. Fill in the numbers in table B.

(A run of tails, however long, counts as one run of no heads)

Table B

Runs of	Frequency
0 Heads	....
1 Head	....
2 Heads	....
3 Heads	....
4 Heads	....
5 Heads	....
6 Heads	....
7 Heads	....
8 Heads	....

b Add your data to the class results on the Example Card

Your name: ....

THINKING SCIENCE
ACTIVITY 13
WORKSHEET p.2

From the class chart of frequencies, answer these questions:

1 Are long runs more frequent or less frequent than short runs? ....

2 About how many more runs of one head did you get than runs of two heads? ....

3 About how many more runs of two heads did the *whole class* get than runs of three heads? ....

4 What can you say about the frequency of runs of tails (0 heads) compared to the total number of spins? ....

5 Do you have equal chances of getting heads or tails? ....

6 Are the two sides (values) of your coin symmetrical? ....

7 Would you be surprised if a coin came down heads twice in a row? ....

8 How many times would it have to come down heads for you to say that the two sides of the coin might not have symmetrical values? ....

▶

Your name: ....

3 *Proportion of heads*

a Make a graph of your results from table A.

Fill in the 'Heads' row on the graph sheet with the number of heads after 1, 2, 3, . . . etc. throws. For instance, suppose your coin landed: H T T H H T H H . . .

After your first throw you had 1 head. After the 2nd throw, you had still only had 1 head. After the 4th throw, you had two heads total, and after 5 throws, 3 heads.

Your entry would look like this:

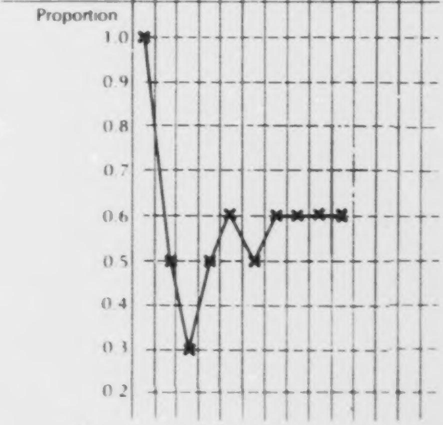
Complete the table from 1 to 15 throws, then for 20, 25, . . . up to 50 throws.

b For each entry, find the *proportion* of heads, and put that in the third row. You may use a calculator, but you need only give the proportion to the nearest decimal point.

c Mark that proportion with a point on the graph directly below. Join the points.

This is an example to show how it is done

Number of throws, *n*:	1	2	3	4	5	6	7	8	9	10				
Heads, *h*:	1	1	1	2	3	3	4	5	5	6				
Proportion heads, *h/n*:	1	·5	·3	·5	·6	·5	·6	·6	·6	·6				



d When you have completed the graph, answer the questions below:

i) Compare your graph to the graphs made by other groups. Are they a similar shape? ....

ii) What proportion do all the graphs seem to be approaching? ....

iii) What is the highest and the lowest proportion of heads after the first four spins?

iv) What is the highest and the lowest proportion of heads after:

	highest	lowest
10 spins	....	....
15 spins	....	....
25 spins	....	....
35 spins	....	....

v) How does the range of proportions change as the number of throws increases?

....

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Your name: ....

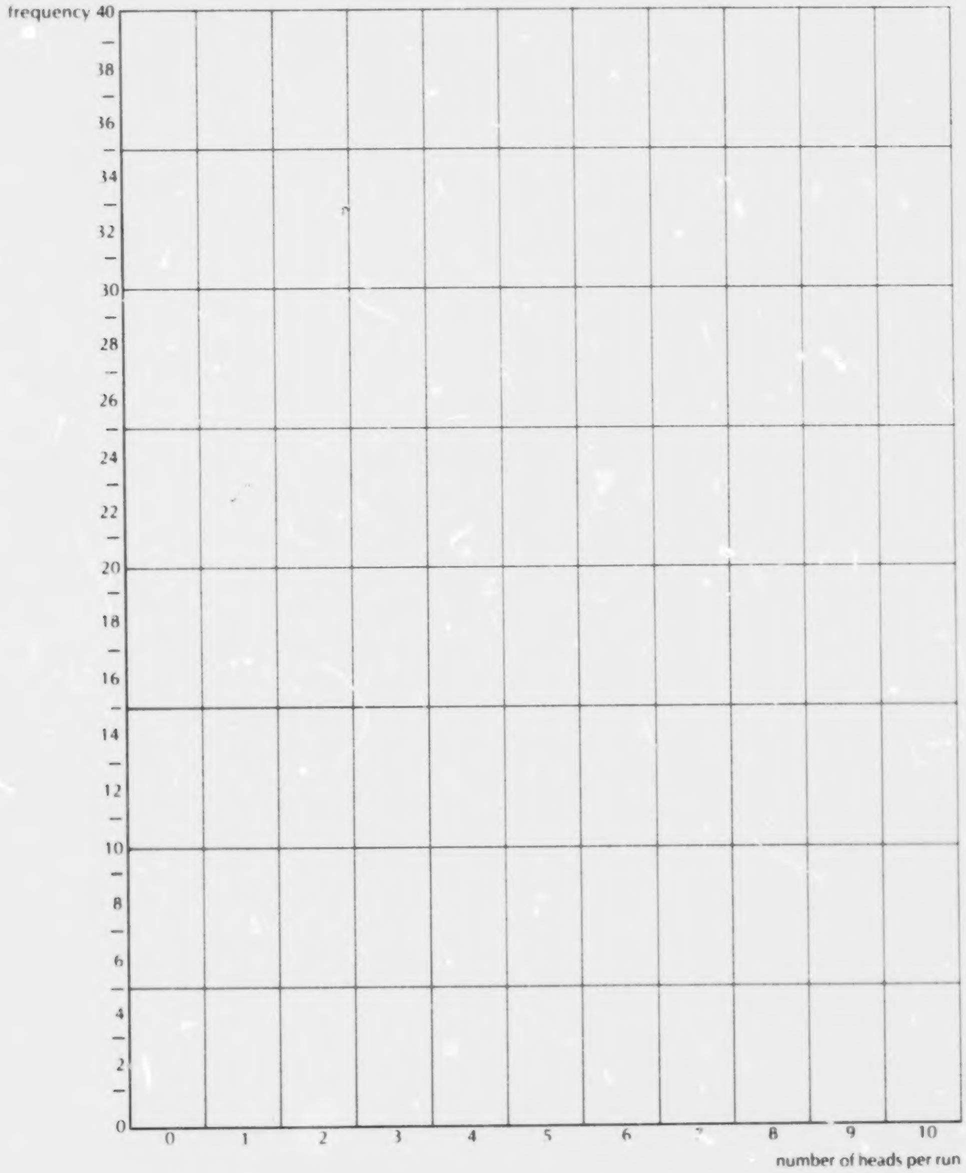
How the proportion of heads changes as the number of throws increases

Number of throws, *n*:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		20		25		30		35		40		45		50
Heads, *h*:																													
Proportion heads *h*/*n*:																													

THINKING SCIENCE
ACTIVITY 13
WORKSHEET p.4

Activity 13: Example Card
Spinning coins

Pattern of runs of heads – Class results



Activity 14: Combinations

Introduction

This activity provides a concrete mental tool that is required for higher level thinking in later activities. Pupils are introduced to strategies for finding all possible combinations of four and five different types of things. They apply the combinations idea in setting up 'fair' tests for the effect of different variables on seed germination, linking with previous work.

Apparatus summary

For demonstration

- A special box with a lamp, four switches, and 'tester button'
- The 'tester button' lights the lamp when switches 1 and 3 are both 'ON'. Switch 2 has no effect. Switch 4 cancels the effect of 1 and 3.

Per group

- Two dishes, cotton wool, cress seeds, labels, tinfoil/black paper to exclude light

For one group

- Two boiling tubes, bungs, alkaline pyrogallol

Per pupil

- Worksheet and paper or notebook

Combinations

Procedure summary

1 In the dark, how many socks must you take from a drawer of black and white socks to be sure of getting a pair?

2 Pupils work on first Worksheet problem together, offering suggestions to each other. After a **while,** suggest a system: list separately the singles and combinations of two, three and four colours. Fifteen different combinations are possible.

3 The second problem has five elements and so is more difficult. Thirty-one combinations are possible.

4 Unobtrusively switch on 1 and 3 on the switch box. Show that with the right combination, the bulb lights when you push the tester button. Pupils work on lists of combinations and try them out **(third problem).**

5 The combination-finding technique is applied to the problem of seed germination. Pupils suggest variables and explore all possible combinations **(fourth problem).**

6 They devise tests for the effect of each variable, and each group sets up one experiment.

7 Results can be observed one or two weeks later.

Procedure details

1 Start with the story of a man trying to find a pair of socks from a drawer full of single black socks and white socks in the dark. What is the least number he has to take to be sure of getting two the same?

2 Now refer to the Worksheet , explain the first problem and let pupils work together to find solutions. This is a good chance to get them to work together, offering suggestions to each other.

Ask individuals and groups what is their strategy for finding combinations – just whatever comes into mind, or do they [illegible] a system? As necessary, suggest a systematic approach: list separately the singles, and combinations of two, three and four colours. Help them to build up a complete list such as: combinations of two, three and four colours.

Help them to build up a complete list such as:

Singles	Pairs	Threes	Fours
R	RG, RB, RY	RGB,	RGBY
G	GB, GY	RGY	
B	BY	RBY	
		GBY	
	4	6	4

total: 15

(This is (2 × 2 × 2 × 2) −1, the −1 being because the 'no colour at all' option is not included.)

3 The second problem has five elements and so is more difficult. The complete solution is:

Singles	Pairs	Threes	Fours	Fives
1	1.2 1.3	1.2.3. 1.2.4	1.2.3.4	1.2.3.4.5
2	1.4 1.5	1.2.5	1.2.3.5	
3	2.3 2.4	1.3.4 1.3.5	1.2.4.5	
4	2.5	1.4.5	1.3.4.5	
5	3.4 3.5	2.3.4 2.3.5	2.3.4.5	
	4.5	2.4.5 3.4.5		
5	10	10	5	1

total: 31 ($2^5 - 1$)

4 Show the demonstration apparatus. Unobtrusively switch 1 and 3 on, and demonstrate that 'With the right combination of switches on, the bulb lights when you push the tester button'. Ask for suggestions for combinations, and let two or three pupils come up and try their ideas.

Pupils then systemise the combinations they wish to try by writing lists on the Worksheet. Again, individuals can try their ideas, but in regular order, recording each in the table.

From able groups you may elicit hypotheses, and then 'what combination should we try now to test this hypothesis?' However, this higher level procedure is not essential to the activity, the main purpose of which is just to elicit all possible combinations of switches.

5 What affects the germination of a seed? This question leads to the application of the combination–finding technique to a real problem. (A seed is said to germinate when its root tip and then shoot tip start to show and grow.)

Elicit possible variables, such as temperature, light, soil, moisture, air. For simplicity each will be given only two values: for temperature, warm or cool; for the others, present or not present. Pupils start to explore all the different possible combinations of these variables, entering ticks and crosses into a table. For four variables there will be 16 possible combinations; for five, 32. (Compare the earlier examples: this time the all–null possibilities are allowable.)

6 Once possible combinations have been established, ask about an experimental test for the possible effect of each variable on germination. This should remind them of earlier work on 'fair' tests.

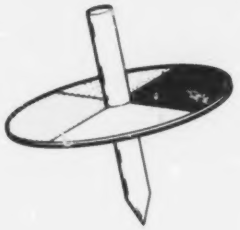
Encourage each group to select one variable they would like to investigate, and devise a specific pair of tests for this variable. (A group wishing to explore air/no air will need extra help. Alkaline pyrogallol can be described as being a chemical which absorbs 'air'/oxygen.)

7 Results can be observed one or two weeks later. The whole class can complete the Worksheet tables with each other's results and variables too. Discuss what seeds need/don't need to germinate as shown by these experiments and what are the minimum number of experiments needed to find this.

Your name: ....

Activity 14: Worksheet Combinations

1 Spinner



This is a coloured spinner.
Suppose you have four colours to choose from:

Blue,	Red,	Yellow,	Green.
(B)	(R)	(Y)	(G)

How many *different* spinners could you make? You may make spinners with one, two, three, or four colours.

Write your combinations here:

e.g.
B   for an all Blue
BRY for Blue, Red, and Yellow.

....
....
....
....

How many different combinations did you find? ....

2 Party

Shireen has a party. She prepares five different sorts of foods:

1 rice,   2 chicken,   3 mixed vegetables,   4 crisps,   5 cake.

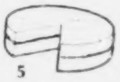
1

2

3

Everyone seems to put a different combination of food on their plates. Some take only one food. Some take mixtures of two, three, or more.

4



5

What different combinations of food could Shireen's friends take?

Just write the number for each food: e.g. '2,4' for chicken and crisps.

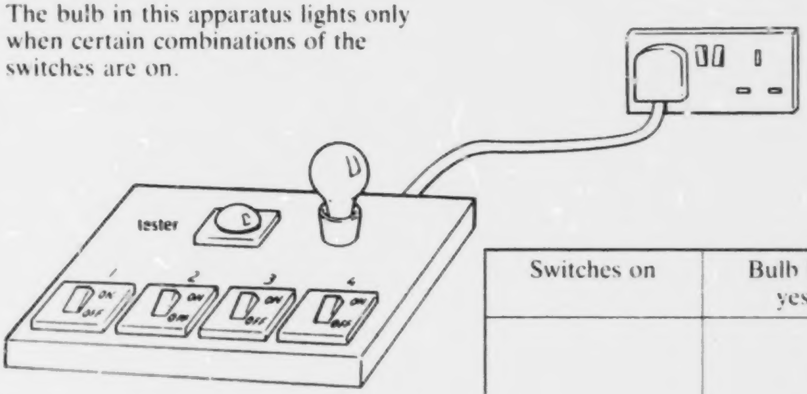
....
....
....
....

What is the total number of combinations possible? ....

Your name: ....

3 Switch box

The bulb in this apparatus lights only when certain combinations of the switches are on.



Switches on	Bulb lights? yes/no

What are all of the combinations of the four switches that you could try?

4 Germination

You can investigate the conditions under which a seed germinates. Think of some variables that might effect the seed, such as

light, ..., ..., ..., ...

What are the possible combinations of these variables you could try?

Make a table like the one below. Put in ticks to show the value of each variable in each trial (e.g. for light, a tick means the seeds have light, a cross means that they do not).

Trial number	Variables Light							Does seed germinate?
1	✓							
2	×							

Design an experiment to test for the effect of one of the variables.

Activity 15: Tea tasting

Probability

Introduction

This is another probability exercise. The problem is, what is the chance of getting four or five (out of five) 0/1 guesses correct? Pupils are often surprised to find how many times it happens that five out of five guesses come out right. We touch on the relevance to decision making in the real world.

Apparatus summary

For demonstration

- A pot of tea, milk, and five tea cups

Per group

- Five coins
- Workcard A
- Example Card

Per pupil

- Worksheet
- Workcard B

Procedure summary

1 Some people say that they can tell whether milk or tea has been put into a cup first. How many would they have to get right before you believed them?

Following Workcard A instructions, one pupil pours, and one records in table 1 on the Example Card. Another pupil tastes each cup and decides 'milk first' or 'tea first'. The subject is marked for number right out of five.

2 Focus on the idea that one could get a lot right by guessing.

3 Five coins can be used to model the possibility of getting five right by chance. However many times they get five heads, will be the same as the number of times someone could get five guesses right by chance.

4 Again following Workcard A, each group makes 25 spins, and puts results in table 2 on the Example Card. Complete the rows. Then, on the Worksheet, pupils plot a graph of number of trials against percentage of five rights, which is seen to tend towards about 3 per cent.

5 If time, collect results for four rights and do the same sort of graph again. This time it tends towards 18 per cent.

6 In a concluding discussion make the point that arguments from single cases are often pretty useless. One needs both enough data, and a measure of the probability that a particular set of results could have happened just by chance.

7 Workcard B problems are for homework or extra classwork.

Procedure details

Some people claim that they can always tell whether milk or tea has been put into a cup first, from the taste. How many, out of five, would they have to get right before you could be sure that they really could do it, and were not just guessing?

If any of the class think they can tell the difference between 'milk first' and 'tea first', let them be the subject to be tested. Or pretend that you can tell, and act as the subject.

Refer to the Worksheet, choose one or two pupils to be 'Pourers', and one or two to be 'Recorders'. The subject turns his/her back on the cups while the Pourer pours the tea, some milk first (MF) and some tea first (TF). The Recorder keeps a record of which is which. This can be done directly into the first row of table 1 on the Example Card. Instructions are on Workcard A.

The subject tastes each in turn, and declares 'milk first' or 'tea first' for each. ('Don't know' is not allowed.) For each cup, the Recorder reports whether the subject is right or wrong, and writes the subject's guess in the second row of the table.

The table helps to avoid confusion which can arise as the answer 'milk first' can be right and can be wrong, and so can the answer 'tea first'. The important thing is whether the answer corresponds with reality or not. The table shows this. After the last cup has been tasted, the last line is used to 'mark' the subject. You end up with none, one, two, three, four or five right out of five.

2 So how many would the subject have to get right before you believed that they really could tell? This is the question for discussion (2 on Workcard A). There is no right answer, but it focuses on the idea that one could get quite a lot right just by guessing, without any real idea of the difference in taste.

3 Point out that five coins can be used to **model** ('to be like') the possibility of getting five right just by chance. Establish that each coin has an equal chance of coming down heads or tails. However many times they get five heads, will be the same as the number of times someone could get five guesses right by chance.

4 Again following Workcard A, as each group finishies its 25 trials, they enter thier results in the second row of table 2 on the Example Card. You, with help, complete the last two rows. Pupils then plot a graph on the Worksheet of number of trials (along the *x* axis). This is exactly analogous to the frequency of heads graph that they plotted last time, but this time the line tends towards about 3 per cent.

5 If you have time, collect results for four rights and do the same sort of graph again. This time it tends towards 18 per cent. In other words, there is nearly a one in five chance of getting four or five tastings right out of five. Anyone who thought that four right answers would be convincing proof that the person really could taste the difference might be inclined to change their mind now.

6 Just how much you can make of the concluding discussion depends a lot on the interest and ability of your class. At least make the point that arguments from single cases are often pretty useless. 'My grandfather's smoked all his life and he's 85' doesn't tell us anything about the relation of smoking to health. Nor does 'five children living near Sellafield nuclear power station have died of leukaemia' tell us much unless we know, at least, the number of children living near Sellafield, the rate of death from leukaemia across the country, and (the point of this activity) the probability that a particular higher rate in one area could have happened just by chance.

7 There is a set of problems on Workcard B for extra classwork or homework.

Just for your own background information, note:

(i) A curiosity in the tea tasting test is the way that the Pourer selects which cups to put which in. They are likely to go for three of one and two of the other – in any case their setting up of the selection will not be random, so this is not, in fact, a good test. For a real test one would need, for instance, a random number generator.

(ii) There are 32 different possible combinations of ways that five coins can fall (2^5). Only one way that five can be heads, hence the 1/32 chance of getting five heads. There are five ways you can get four heads (any one of five coins falling tails up). So a total of six chances out of 32, near 18 per cent, of getting four or five heads.

Workcard B Answers

1a X b X or Y
2a 100 million b 100 million c half, 50 per cent etc. d none
3 XX – female; XY –male. 50 per cent.
4a Cannot tell; 50-50 chance; Mr Smith.
5 e.g. toss two coins, one of which has two heads (= X).
6a 1/6 b 1/6 c same
7 Has an equal chance of landing on any side.

Your name: ....

THINKING SCIENCE
ACTIVITY 15
WORKSHEET

Activity 15: Worksheet
Tea tasting

Probability

Numbers of 'Right' answers (Heads) out of five:

trial number

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25

Out of 25 trials, how many *five* rights did you get? ....

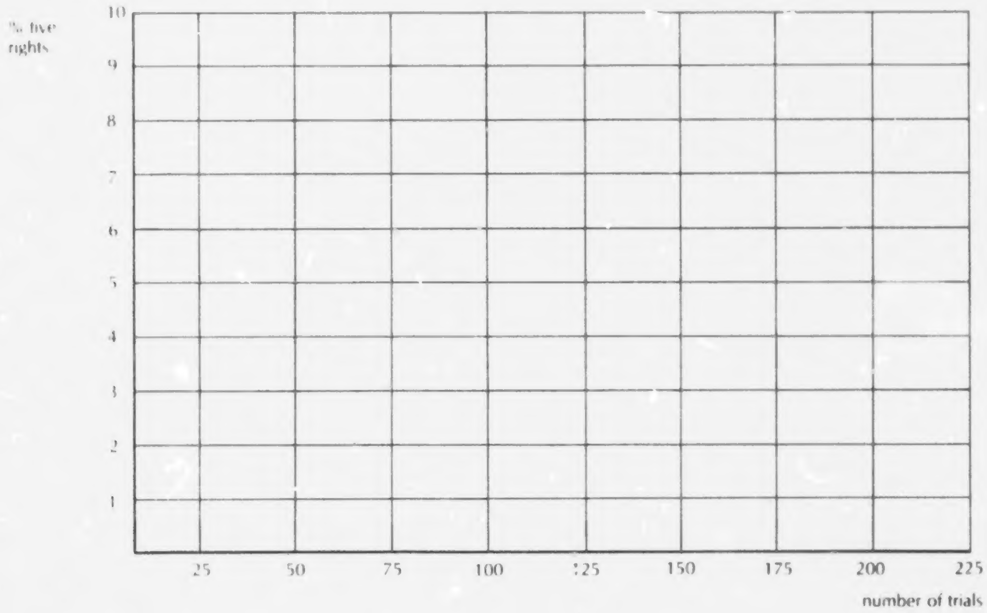
how many *four* rights? ....

What seems to be the chance (out of 25 trials) of getting five tea tastings right just by guessing? ....

What seems to be the chance (out of 25 trials) of getting *four or five* tea tastings right just by guessing? ....

From all of the class results together, what seems to be the chance that someone could guess correctly in five out of five cups of tea, whether the milk or the tea had been put in first? ....

Graph to show the percentage of five rights after 25, 50, 75, etc. trials.



To what percentage does the line seem to be tending? ....%

Activity 15: Workcard A Tea tasting

Probability

Somebody says she can always tell whether milk or tea has been poured first.

How could you test them?

1 Prepare five cups of tea. Put milk first in some, tea first in others.

Someone tastes each one. For each cup, they say 'tea first' or 'milk first'.

You mark them right or wrong.

2 Discuss how many times a person has to be *right*, out of five, for you to be sure that she is not just guessing.

3 Coin spinning can be used to model tea tasting.

If the coin comes up heads, that's *right*.
If the coin comes up tails, that's *wrong*.

With coins, it is just chance whether they fall heads or tails. If you spin five coins, and get five heads, that is like getting five cups of tea right by chance.

Spin five coins. Count the number of 'Rights' (heads). Put this number under trial number 1 in the table on your Worksheet. Do a total of 25 trials, each time with five coins. For each trial, write the number of 'Rights' in the table.

4 Answer the questions on your Worksheet.

5 All of the class results will be collected together. Use these results to plot a graph to show how the *percentage* of five rights changes as you do more and more trials.

Activity 15: Workcard B
Tea tasting

Probability

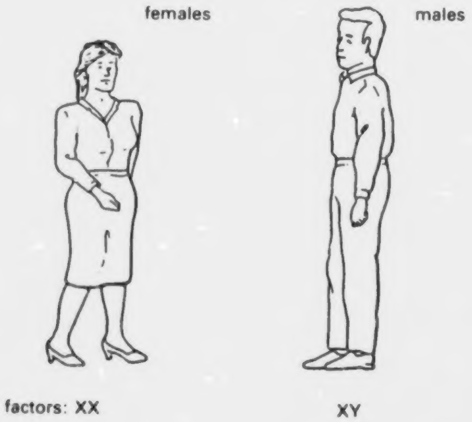
Problems

Boy or Girl

Each body cell in a woman contains two 'sex factors' which are alike. Both are 'X factors'.

Each body cell in a man also contains two 'sex factors' but they are different. One is an 'X factor', like the ones found in a woman. The other is a 'Y factor'.

So:



1 Egg cells and sperm cells are different from other body cells. They can only contain one sex factor.

  a In a female, the sex factor must be what?
  b In a male, the sex factor could be what?

2 If a man's body has made 200 million sperm cells,

  a How many are likely to contain an X factor?
  b How many are likely to contain a Y factor?
  c What proportion contain a Y factor?
  d What proportion of the eggs a woman makes contain a Y factor?

3 A baby is made when one of a man's sperm cells joins with one of a woman's egg cells.

Female: all the eggs have one X factor.
Male: half the sperm have one X factor.
half the sperm have one Y factor.

Fertilisation: one egg + one sperm grows into a baby

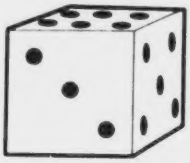
  a How many combinations of factors can you have? Write a list.
  b Now write next to each combination the sex of the baby.
  c What are the chances of a baby being a girl?

▶

4 a If Mr and Mrs Smith already have five sons what do you think will be the sex of their sixth baby?
  b Why do you think so?
  c Was it Mr or Mrs Smith who determined the sex of the baby?

5 a Can you think of a way that you could model how the sex of a baby is determined? (Remember how you modelled tea tasting.)
  b How could you test your model to see if it was like real life?

Dice



A die has six sides.
Each has a different number on it.
A die is symmetrical.

6 a If you throw one die, what is the probability (out of 6) that you will get a 4?
  b What is the probability that you will get a 1?
  c Is the probability of getting a 6 more, less, or the same as the probability of getting a 3?
  d Why do you think so?

7 What do we mean when we say that the die is symmetrical?

Activity 15: Example Card
Tea tasting

Table 1 **Right or wrong**

Cup :	1	2	3	4	5
MF or TF :					
Subject's guess:					
Right or wrong:					

Table 2 **Percentage of five rights**

Group	1	2	3	4	5	6	7	8	9	10
Number of trials	25	25	25	25	25	25	25	25	25	25
Number of five rights										
Total trials so far	25	50	75	100	125	150	175	200	225	250
Total five rights so far										
Percentage of five rights										

Activity 16: Interaction

Variables

Introduction

We come back to variables again, but this time look at examples where there is interaction between two variables i.e., the effect of two variables together is greater (or less) than the simple sum of the effect of each variable on its own.

Apparatus summary

Per group

Experiment 1

- Four test tubes (A, B, C, D) containing suspension of dried yeast in water and a drop of lemon juice; sugar
- Ruler with mm marking
- Water bath at about 35 °C

For demonstration

Experiment 2

- Beaker half full of water, Bunsen, gauze and tripod
- Three test tubes (1, 2, 3) with iron nails, *set up in advance*. 1 is dry, 2 has boiled water (no air), 3 has water and air

Per pupil

- Worksheet

Procedure summary

1 Recall work on variables, values, input and output. Now they are going to look at the effect of *two* input variables on one output variable.

2 Yeast. Discuss whether yeast is alive etc. and then concentrate on respiration, need for food, need for warmth. The investigation is about the effects of *food* and *warmth* on respiration.

3 First part of Worksheet: discuss ideas and then they complete a summary of a good 'fair' test – at least: one without sugar, not warmed; one with sugar not warmed; one without sugar, warmed. But to see the effect of both variables together, we also need one with sugar, warmed.

4 While waiting, introduce the next experiment, about rust. One suggested cause may be 'water'. A look at heated water shows air bubbles. Maybe air in water causes rust. Pupils start part 3 of the Worksheet. Conclude that you need one with dry air, one with water from which air has been removed. For the effect of two variables together, we need one with air and water. From test tubes prepared a week ago, summarise: 1 – no rust; 2 – no rust; 3 – rust. Neither variable alone has an effect, but both variables together make iron rust. They **interact**.

5 Pupils measure the froth in each yeast experiment and complete the table in part 2. A – nothing; B – very little; C – little or nothing; D – a lot. Talk through the idea of interaction again.

Procedure details

1 Remind pupils of the work done previously on variables, values, input, and output. In this activity they are going to look at the effect of *two* input variables together on one output variable.

2 The first experiment is about yeast. Relate yeast to other experiences – maybe bread or wine or beer making at home, or in experiments in school. Discuss whether yeast is alive, dead, or non-living, eventually suggesting that it is alive. The dried yeast you buy is 'dormant' (like sleeping), but if you mix it with water, it can become active again.

If yeast is alive, then what can we say about it? From characteristics of living things which pupils suggest, concentrate on:

- respiration (preferable to 'breathing' if possible),
- need for food,
- need for warmth.

In this experiment they are going to investigate the effects of the input variables *food* and *warmth* on the output variable respiration. Some questions for discussion:

- What sort of food does yeast like?
  Simple organism likes simple food – sugar.
- What do we mean by warmth?
  We could choose to compare room temperature with body temperature (say 37 °C).
- How do we measure the amount of respiration?
  By the amount of gas given off – could look at the amount of froth.

3 The problem now is to design an experiment to test for the effects of sugar (food) and warmth on the amount of gas given off. **Refer to** the Worksheets, and explain what is needed for the first part. After **five minutes for** planning experiments, discuss their ideas with groups or with the whole class. Get them to complete the second table as a summary of a good 'fair' test. The minimum we are aiming for is:

- one without sugar, not warmed
- one with sugar, not warmed
- one without sugar, warmed

This would give a 'fair' test for each of the variables separately. But we are interested in more than this. We want to see if both variables acting together produce an effect over and above the effect produced by each separately. So we also need:

- one with sugar, warmed

Pupils set up the experiments.

4 While they are doing that, put a large beaker of water to heat. Do not let it get near to boiling. When the yeast experiments are set up, they must be left for about 25 minutes to see any effect. While waiting, you can introduce the next experiment, about rusting.

What causes iron to rust? A common suggestion may be 'water'. But does water alone make iron go rusty? Look at the water being heated in the large beaker. It is far from boiling, but there are bubbles of gas in it. This is air. Normal water contains air dissolved in it. When we say 'water causes rust', maybe the air in the water has something to do with it as well.

How could we design an experiment to test for the effect of air and water separately? You can get water without air by boiling it; and air without any water by putting in a drying agent such as silica gel. Pupils start to complete part 3 of the Worksheet. Discuss their ideas, coming to the conclusion that what you need is:

- one test tube with nail and dry air,
- one test tube with nail and water from which air has been removed.

This, possibly with one test tube with a nail in a vacuum, is enough to test for the effect of the water and air variables separately. But to see if the two variables together have an effect, we must have,

- one test tube with nail, air and water.

Show the test tubes you have prepared, explaining that you set them up a week ago. Use a table like that in part 3 of the Worksheet to summarise the results: 1 - no rust; 2 - no rust; 3 - rust.

Neither variable alone seems to have any effect, but both variables together do make iron go rusty. The variables **interact** with one another. Together they produce more effect than either does by itself.

5 By now the yeast experiment should be developing. Pupils measure the amount of froth in each test tube and complete the table in part 2, using phrases such as 'little gas', or 'a lot of gas'. Different groups report results, which you could summarise on the board. Results may be something like:

A: nothing
B: very little
C: little or nothing
D: a lot

Talk through the idea of interaction again, and let them do the questions in part 2.

Your name: ....

Activity 16: Worksheet Interaction

Variables

Two *input variables* that might affect the activity of yeast are:

- **warmth,**
- **food.**

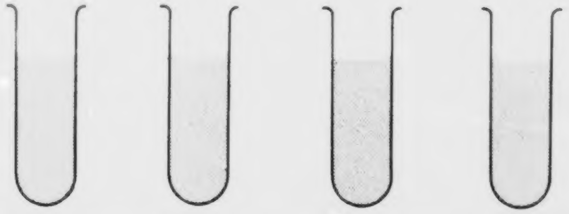
(for yeast, a good food is sugar)

The *output variable*, by which we can measure the activity, is the **amount of gas** produced.

1 Yeast – experiment

Try to design a fair test for: the effect of warmth, the effect of sugar, and the effect of both together on the activity of yeast.

Imagine you have four test tubes, each containing yeast in water. In the table under the test tubes, write whether it should have sugar, and whether it should be kept warm or not.



Input variables	A	B	C	D
Sugar ('yes' or 'no')				
Temperature ('warm' or'not')				

What would you look for in the four test tubes?

....

After you have completed your table, discuss it with your teacher. Then complete this table with the conditions you will *actually* use:

Input variables	A	B	C	D
Sugar ('yes' or 'no')				
Temperature ('warm' or'not')				

2 *Yeast – results*

Summarise the results of the yeast experiment in this table:

Input variable: *sugar*	Input variable: *warmth* not warm	 warm
without sugar	A	B
with sugar	C	D

From your results, answer these questions:

1 In which test tube was the most gas produced? ....

2 What were the conditions (warm?, sugar?) in this test tube?

....

3 How did the amount of gas in this test tube compare with the amount of gas in test tubes:

B, which had no sugar but was warm? ....

C, which had sugar but was not warm? ....

4 Write a sentence about yeast, sugar, and warmth using the word **interaction**.

....

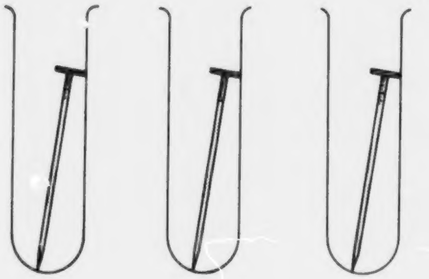
....

3 *What makes iron go rusty?*

a Design a fair test to find the effect of

water alone,
air alone,
water and air together,

on an iron nail.



Each test tube has a clean iron nail. What would you put in each?

Below each test tube, write what you would put in it:

....

....

the input variables are: ....

the output variable is: ....

b Summarise the results of the rust experiment in this table:

Input variable: *air*

Input variable: *water*	no air	with air
no water	(no experiment)	1
with water	2	3

Is the effect of the water and air together greater than the effect of either the water or the air? ....

Write a sentence about rusting, air, and water, using the word **interact**.

....

....

Activity 17: The behaviour of woodlice **Correlation**

Introduction

Through looking at the behaviour of woodlice in choice chambers pupils are encouraged to review ideas about variables, their possible combinations, notions of 'fair' tests and probabilities. They are led to consider the need for large sample numbers and replication, particularly in biology, to allow for the innate variation of organisms (strictly speaking, the randomisation of variables that cannot be controlled). This activity lays the groundwork for introducing correlation.

Apparatus summary

Per group

- Choice chamber, gauze, silica gel, black paper shields, 20 woodlice
- Optional: a lamp

(Five groups, each with 20 woodlice, give a total sample of 100 – useful for percentages.)

Per pupil

- Worksheet

Procedure summary

1 First section of Worksheet: pupils think about where woodlice might be found, and of conditions they might like – especially: light/dark and wet/dry.

2 Woodlouse preferences could be explored with 'either/or' boxes.

3 But to investigate combinations of variables, **the choice chamber is ideal. Pupils record the condition in each part of the choice chamber and predict where woodlice would go if they had *no* preference amongst the conditions.**

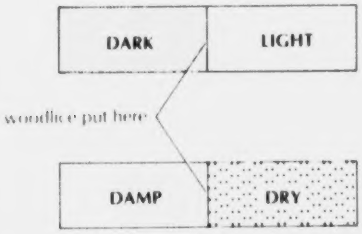
4 Demonstrate the apparatus and show how to introduce woodlice. After five minutes, each group records the distribution in their choice chamber, and class results are collected on the **Worksheet**

5 Pupils look at dark/light comparisons, and then at damp/dry comparisons. Then they look at all four conditions at once to see if there is interaction between the two conditions.

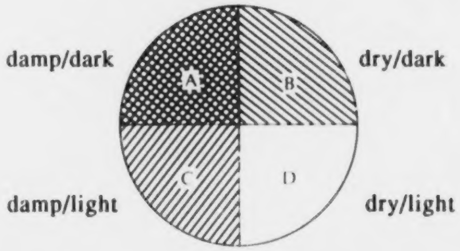
Procedure details

1 Show pupils some woodlice. Go through the first section of the Worksheet with the whole class or with groups. The point is to make pupils think about where woodlice might be found, to think of variables in conditions they might like, and then to concentrate specifically on: light/dark, and wet/dry.

2 Discuss how we could see if woodlice preferred one condition to another (recall the 'fair' test notion). One way would be to offer the woodlice 'either/or' choices. For example, use boxes with two 'rooms':



3 But what about combinations of variables? (Remember combinations activities and the interaction experiments). Lead to the four possibilities of dry/light, dry/dark, damp/light, damp/dark. Introduce the choice chamber as a way of providing all of these possibilities.



Pupils complete a table showing the conditions in each part of the choice chamber. They say where they would *expect* woodlice to go in the chamber if they had *no* preference amongst the conditions offered. The distribution would be random, we cannot predict how many would go into each part. With large numbers, the trend would be towards equal numbers in each compartment.

4 Show how the apparatus is set up and how to introduce woodlice. After about five minutes, each group records the distribution of woodlice in their choice chamber. Group results are collected together on the **Worksheet table**. (Discuss why results are aggregated.)

5 Pupils look first at dark/light comparisons, and then at damp/dry comparisons (the strategy is outlined explicitly on Worksheet). Finally they are asked to draw conclusions by looking at all four conditions at once. They deduce the order of woodlice preferences, and hence the primary factor (dark or damp?) determining their distribution. With an able group you could try measuring the interaction. Is the ratio of damp/dark to dry/light greater than the product of the ratios of damp/light to dry/light and dry/dark to dry/light?

Your name: ....

Activity 17: Worksheet The behaviour of woodlice

Correlation

1

Woodlice are common animals. What sort of places do you find them living in?

....

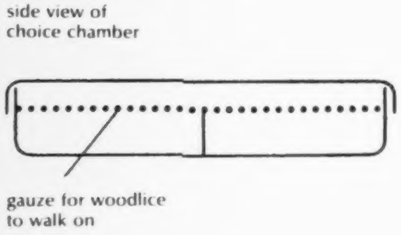
What are some of the variables of the conditions that woodlice may like?

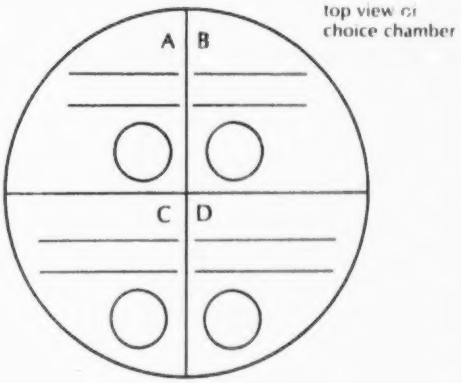
....

Discuss how you could set up an experiment to see if woodlice preferred *dark* to *light*, *damp* to *dry*.

2

If you want to test two variables at a time (e.g. damp/dry and light/dark), you can use a **choice chamber**:


side view of
choice chamber
gauze for woodlice
to walk on


top view of
choice chamber
A
B
C
D

In each of the areas A, B, C, D in the top view above, write what combination of variables it has (dark/damp; light/damp etc.).

Your name: ....

3

Suppose we put 20 woodlice into the middle of the choice chamber. They start to walk about.

If they didn't mind which of the conditions they lived in, where would you expect to find them after 5 minutes?

Most in A ....
Most in B ....
Most in C ....
Most in D ....
Equal numbers in A, B, C, and D ....
You cannot tell ....

4

Now put 20 woodlice into the choice chamber to see what actually happens.

Look at your woodlice after 3 minutes. Count the numbers in each compartment and fill them in on the diagram of the choice chamber in part 2 of the Worksheet.

5

All the class results will be added together. Why?

....

Complete the class results table. Add up the totals for woodlice found in each compartment.

Group	A dark/dry	B dark/damp	C light/dry	D light/damp
1				
2				
3				
4				
5				
6				
7				
8				
Totals				

Your name: ....

6 *Light or dark?*

a How many woodlice are there in the dark compartments? dark/dry + dark/damp = ...

b How many woodlice are there in the light compartments? light/dry + light/damp = ...

c What can you say about woodlice preferring light or dark?

....

7 *Damp or dry?*

a How many woodlice are there in the damp compartments? light/damp + dark/damp = ...

b How many woodlice are there in the dry compartments? light/dry + dark/dry = ...

c What can you say about woodlice preferring dry or damp?

....

8

Now think about all four compartments.

a What conditions do woodlice like best?

dry/dark ....
dark/damp ....
light/dry ....
light/damp ....

b What conditions do woodlice like least?

dry/dark ....
dark/damp ....
light/dry ....
light/damp ....

c Where is a woodlouse happier, in the dark (where it might be dry) or in the damp (even if it is light), or can't you tell? Explain your reasons.

....

....

....

Activity 18: Treatments and effects

Introduction

In physical sciences, relationships between variables can often be described unambiguously ('proportional to', 'inversely proportional', or defined in terms of an equation). As the woodlouse activity (Activity 17) emphasised, living things incorporate so many uncontrollable variables that their behaviour cannot be reliably predicted. **Thus,** to explore possible relationships between causes and supposed effects is not straightforward. **Correlational reasoning** is the process used to assess the strength of relationships between variables, and this activity provides examples to show pupils what is meant by **correlation**.

The results of experiments carried out on various plants and animals are used by students to construct a 2 × 2 contingency table, to look for positive, negative, or zero correlations between treatments and their effects.

Apparatus summary

Per group

- Workcard pack of 20 treatment/effect cards. (Material for five different packs of cards is provided.)

Per pupil

- Worksheet
- Example Cards A and B

Procedure summary

1 Introduce example of effect on carrots of 'Grocaro'. Grocaro is the treatment; size of carrots the effect.

2 Summarise the possibilities of treatments and effects in a 2 × 2 table. Discuss the need for replication in experiments with living material – treatments must be tried on a sample.

3 Show results from Professors Boffin and Brainbox's experiments. **(Example Card A) For Boffin's**, comparing the number of large carrots treated (A) with the number of large carrots not treated (B) suggests that 'Grocaro' does increase the size of carrots. With Brainbox's results, it is necessary to compare 'proving' cases and 'disproving' cases. A+D=24, C+D=16, so 'Grocaro' improves the size of carrots.

4 Each group now works on a set of cards, sorting into four categories, counting and filling in the 2 × 2 tables. Strategies given on the Worksheet help them to estimate **correlational strength**.

5 **Class results are summerised (Example Card B) and the correlation compared.**

Procedure details

1 Introduce an example. 'We want to see if spraying carrot plants with a new chemical called 'Grocaro' makes them bigger. If it doesn't affect them, or if it makes them smaller, we will stop making the chemical and try to find a new one instead.' The problem can be summarised:

Does 'Grocaro' make carrots bigger?
(TREATMENT) (PLANT) (EFFECT)

'Grocaro' is the input variable, or treatment; size of carrots is the outcome variable or effect.

2 How could we test the effect of 'Grocaro'? Suggestions could include treating some carrots with 'Grocaro' and leaving others untreated.

Summarise the possibilities:

	Treatment with Grocaro	**No treatment** without Grocaro
Effect bigger carrots	A	B
No effect usual size carrots	C	D

Should we treat just one carrot and not another? Discuss the need for replicating experiments, particularly those using living material because of its variability. No two living things are the same so a treatment must be tried on a sample of the organisms to be sure of its general effect.

3 **Review Example Card A results from Professors Boffin and Brainbox's experiments. For Boffin's results, comparing the number of large carrots treated (A) with the number not treated (B) it seems that 'Grocaro' does increase the size of carrots.**

In Brainbox's results, comparing A with B shows very little effect. However, boxes C and D suggest that *without* treatment, more carrots do *not* grow large. To follow this argument, introduce the idea of 'proving' cases and 'disproving' cases. If the treatment works, there will be larger numbers both of carrots that have had 'Grocaro' and do grow large, and of carrots that have not had 'Grocaro' and do not grow large. These are the proving cases, boxes A and D. Conversely, boxes B and C contain the disproving cases. Comparing Brainbox's proving cases (12+12) with disproving cases (8+8) does seem to show that 'Grocaro' improves the size of carrots. There is no need to labour this point now. It is not easy, and pupils will get practise applying the principle to their own results.

4 Describe the class as a group of scientists trying to increase the productivity of various plants and animals. **Each group uses a set of** cards and Worksheet. Go through the first section, helping to complete the line defining the group's particular problem.

Explain how to sort the cards into four categories, counting and filling in the table with the total for each category. Once they have their results in the 2×2 tables the students should find out if the treatments seem to work or not. Help them to use the strategies outlined on the Worksheets.

Looking at any two cells with a common attribute (e.g. A:B, A:C), can they say 'The treatment had an effect because more plants/animals which had the treatment show an effect than plants/animals that did not have the treatment?' If they cannot give a very positive answer to question 4 (and the figures ensure that they cannot) they must go on to compare two pairs of cells to make two comparisions. This is spelt out in the two columns on page 2 of the Worksheet. The terms 'proving' and 'disproving' cases refer to the (probably unspoken) initial hypothesis: that the treatment produces a positive effect.

Comparing 'proving' cases with 'disproving' cases shows the type of correlation to be found. The word correlation is emphasised and **explained in the terms summarised on Example Card A.**

5 Results of the whole class are now **summarised on Example Card B and the different correlations compared.**

Results for each set of cards

Sample size for each set is 20 organisms.

Treatment (T) and Effect (E)

Examples	A +T, +E	B −T, +E	C +T, −E	D −T, −E	Correlation A+D:B+C
carrots/Grocaro					
● Professor Boffin	17	1	3	19	36:4 positive
● Professor Brainbox	12	8	8	12	24:16 positive
sheep/red pills	7	7	1	5	12:8 positive
cows/green pills	7	7	5	1	8:12 negative
pigs/brown pills	8	3	7	2	10:10 zero
wheat/fertiliser	6	7	2	5	11:9 positive
roses/leaf shine	4	7	3	6	10:10 zero

Your name: ....

Activity 18: Worksheet Treatments and effects

Correlation

Each card shows an *effect* – for instance a lot of wheat or a little wheat; a lot of wool or a little wool.

Some cards show a *treatment* – for instance, red pills or fertiliser.

The question is: does the *treatment* have any *effect*?

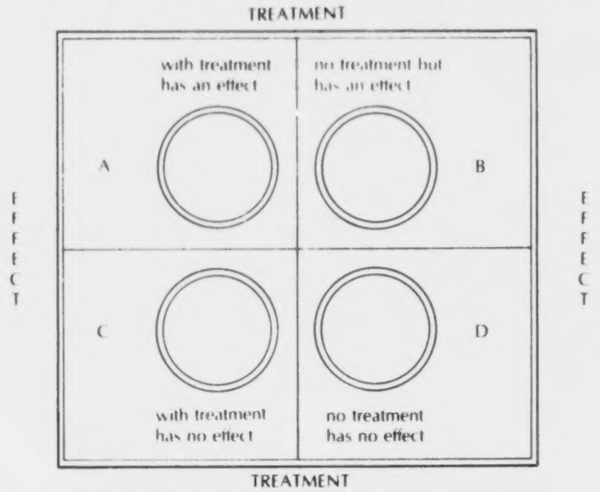
Your group's problem

Animal or plant: ....

Treatment: ....

Possible effect: ....

Count the cards into four piles and fill in the numbers in the circles:



TREATMENT
with treatment has an effect
no treatment but has an effect
A
B
EFFECT
EFFECT
C
D
with treatment has no effect
no treatment has no effect
TREATMENT

1 In which boxes are the animals or plants which show a *positive* effect? (circle one) A B C D

Have more of the animals/plants in these boxes been (tick one)

treated? ....

not treated? ....

or are there nearly the same numbers? ....

2 In which boxes are the animals or plants which have all been treated? (circle one) A B C D

Do more of these show (tick one)

a positive effect? ....

show no effect? ....

or are the numbers nearly the same? ....

Your name: ....

3 In which boxes are the plants or animals which are not treated? (circle one) A B C D

Do more in these boxes (tick one)
show an effect? ....
not show an effect? ....
or are the numbers nearly the same? ....

4 Overall, do you think that the treatment has (tick one)
a positive effect? ....
a negative effect? ....
or are you not sure? ....

Why do you think so?

....

Putting it together

So far, you have compared the boxes two at a time. You really need to be a able to compare all of your data (all four of the boxes) at once

If a) more of the treated animals show an effect,
and b) more of the untreated animals do not show an effect,
then the treatment works.

Boxes A and D are the ones that prove that the treatment works.

If a) more of the treated animals do not show an effect,
and b) more of the untreated animals do show an effect,
then the treatment does not work.

Boxes B and C are the ones that prove that the treatment does not work. (*Disprove* the treatment.)

Looking at all of your results, can you now say whether or not the treatment has an effect?

....

What sort of *correlation* do your results show?
positive correlation ....
negative correlation ....
no correlation ....

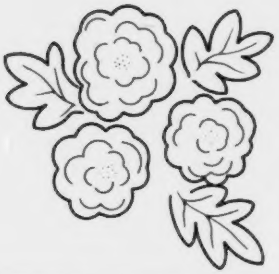
Activity 18: Workcards Treatments and effects

Correlation

Cards

The following 10 sheets should be cut up to make five packs of 20 cards each.

▶



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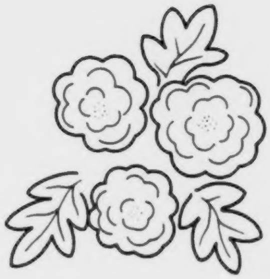

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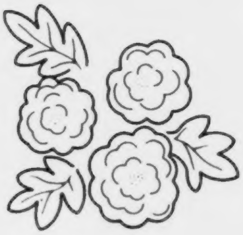

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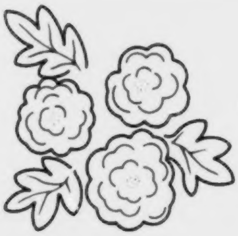

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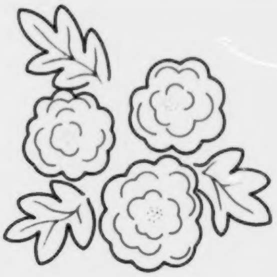

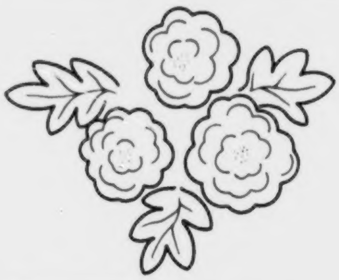

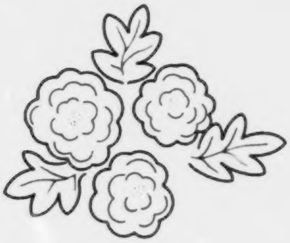

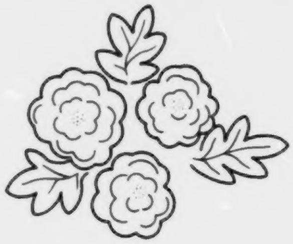

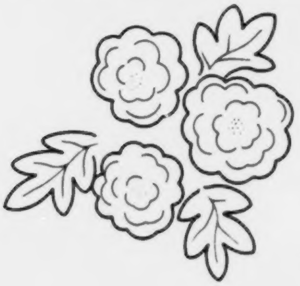

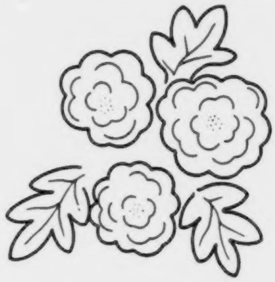

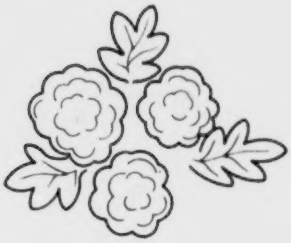

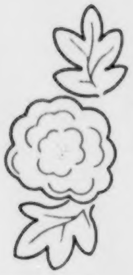

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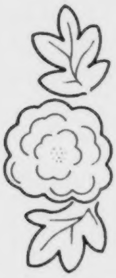

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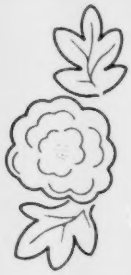

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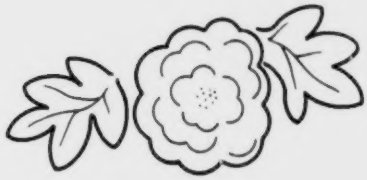

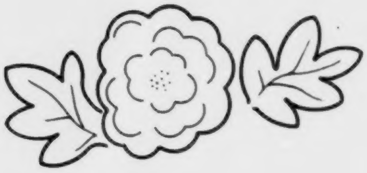

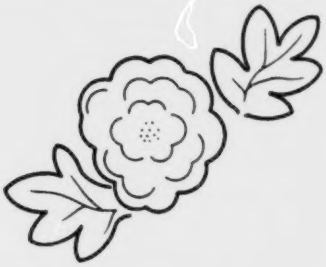

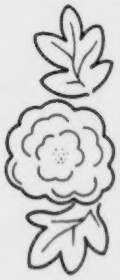

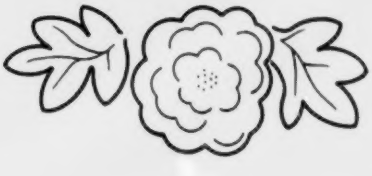

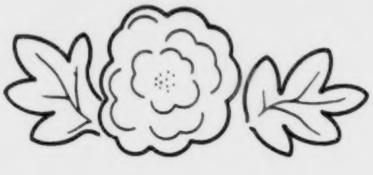

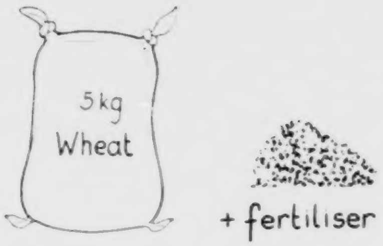
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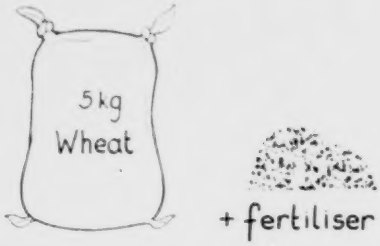
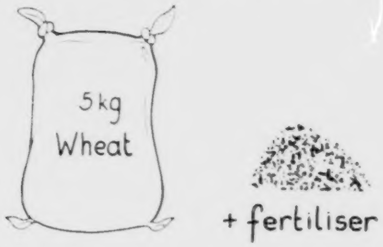
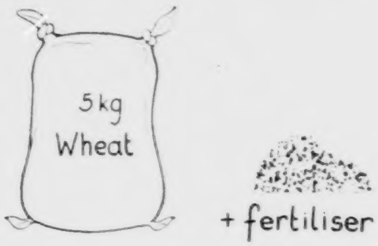
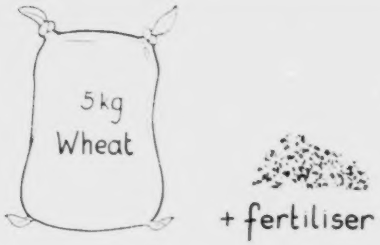
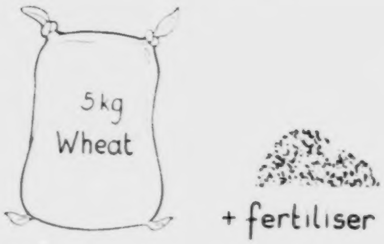
Wheat
+ fertiliser

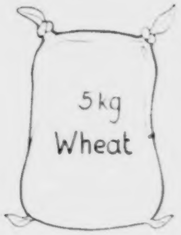

5 kg
Wheat
+ fertiliser


5 kg
Wheat
+ fertiliser


5 kg
Wheat
+ fertiliser


5 kg
Wheat
+ fertiliser


5 kg
Wheat
+ fertiliser


5 kg
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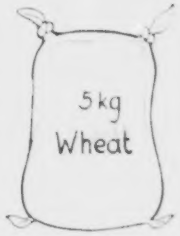
5 kg
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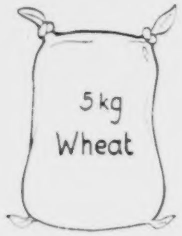
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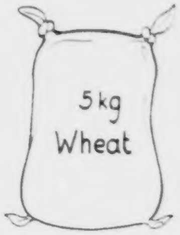
Wheat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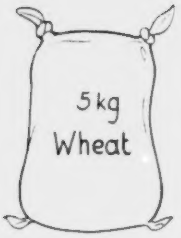
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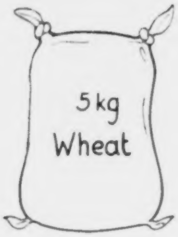
5 kg
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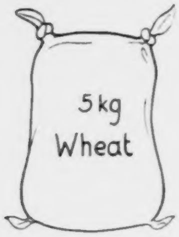
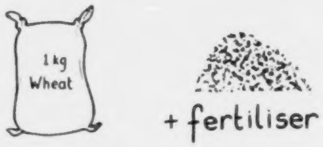
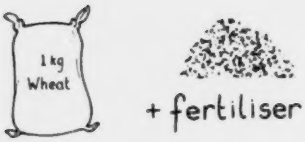
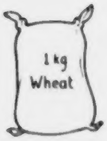
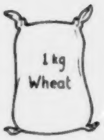
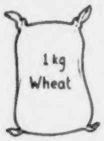

5 kg
Wheat


1 kg
Wheat
+ fertiliser


1 kg
Wheat
+ fertiliser


1 kg
Wheat


1 kg
Wheat


1 kg
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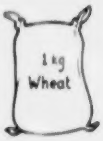
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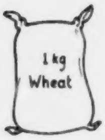
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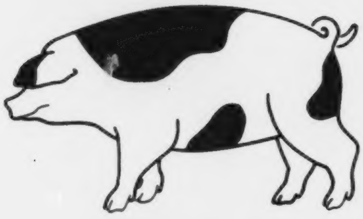
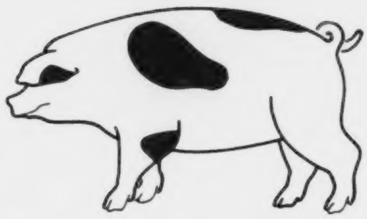
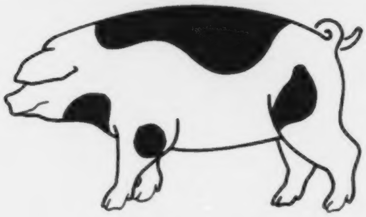


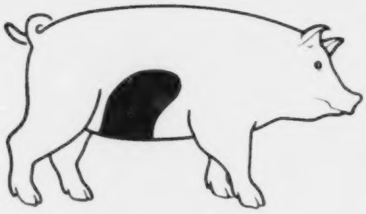
+ brown pill



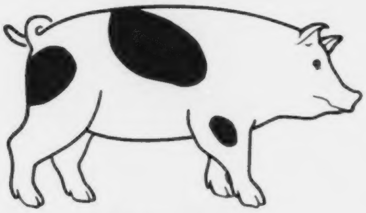
+ brown pill



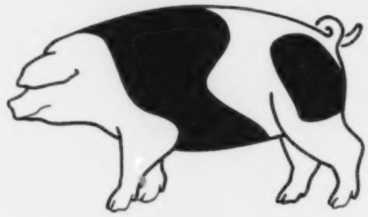
+ brown pill



+ brown pill



+ brown pill



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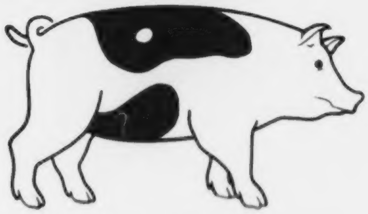

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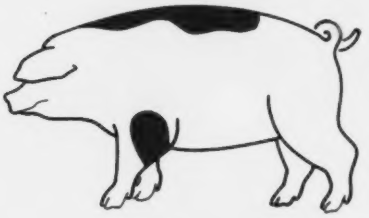

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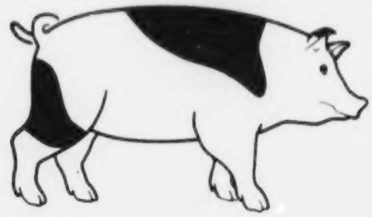
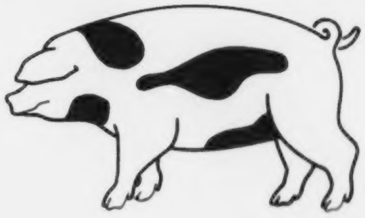
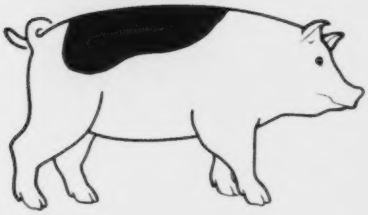
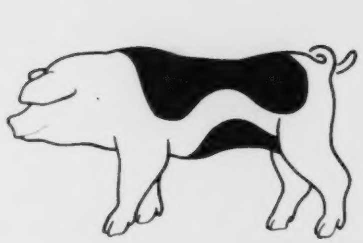
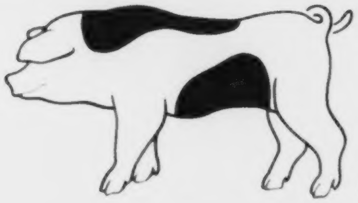




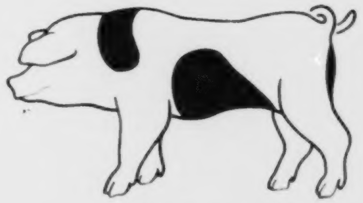




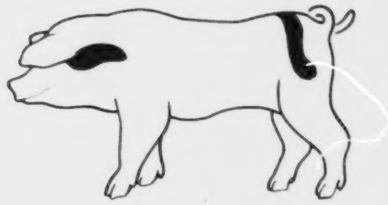
+ brown pill



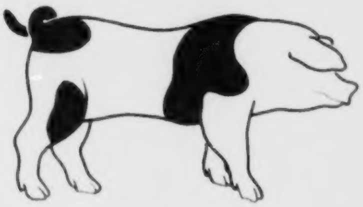
+ brown pill



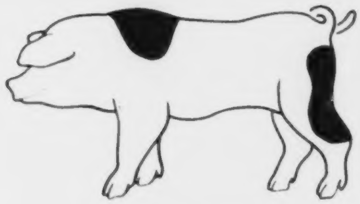
+ brown pill



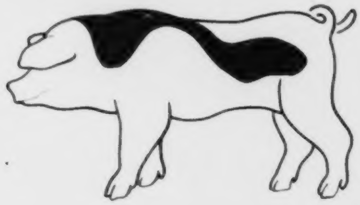
+ brown pill



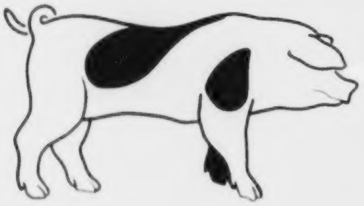
+ brown pill

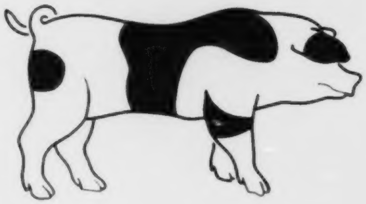


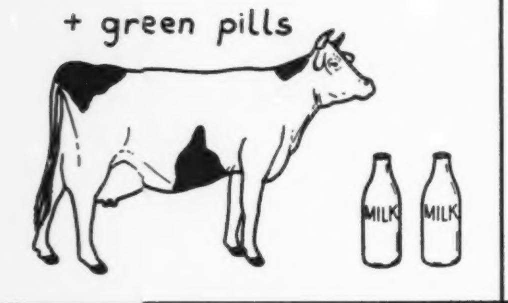
+ brown pill



+ brown pill



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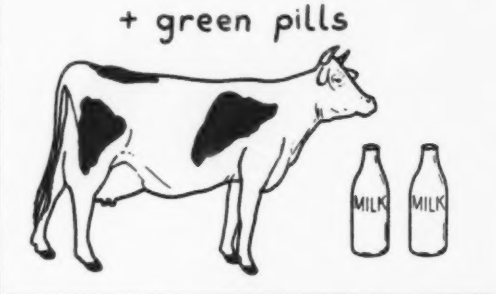
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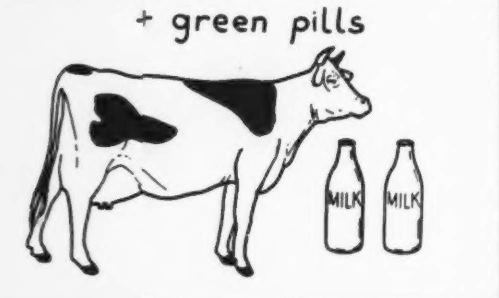
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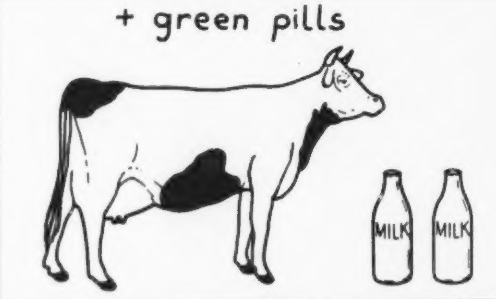
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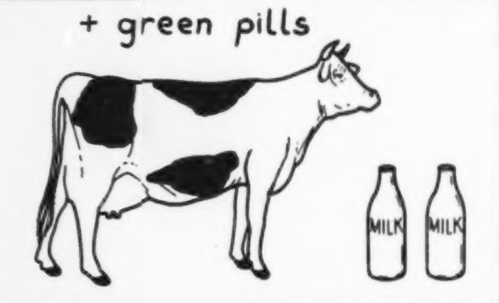
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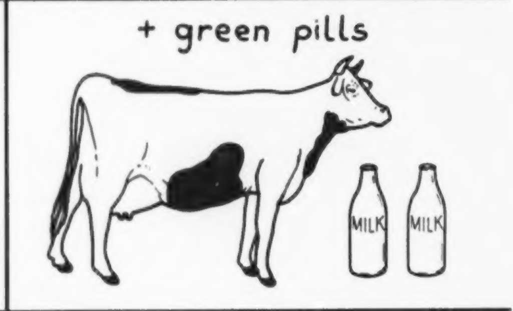
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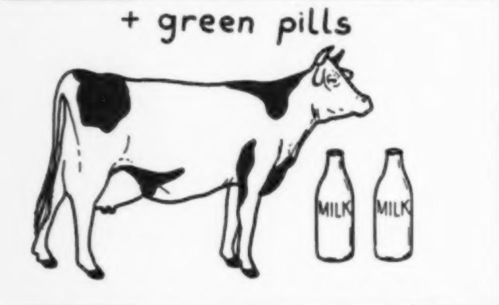
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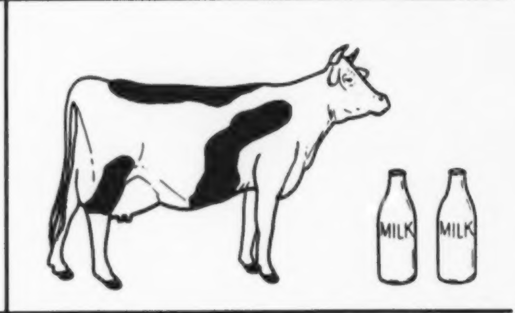
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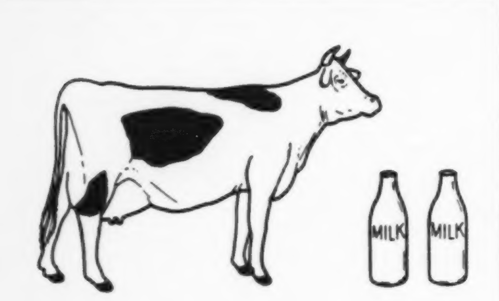
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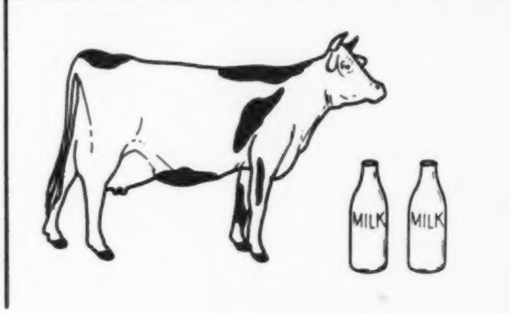
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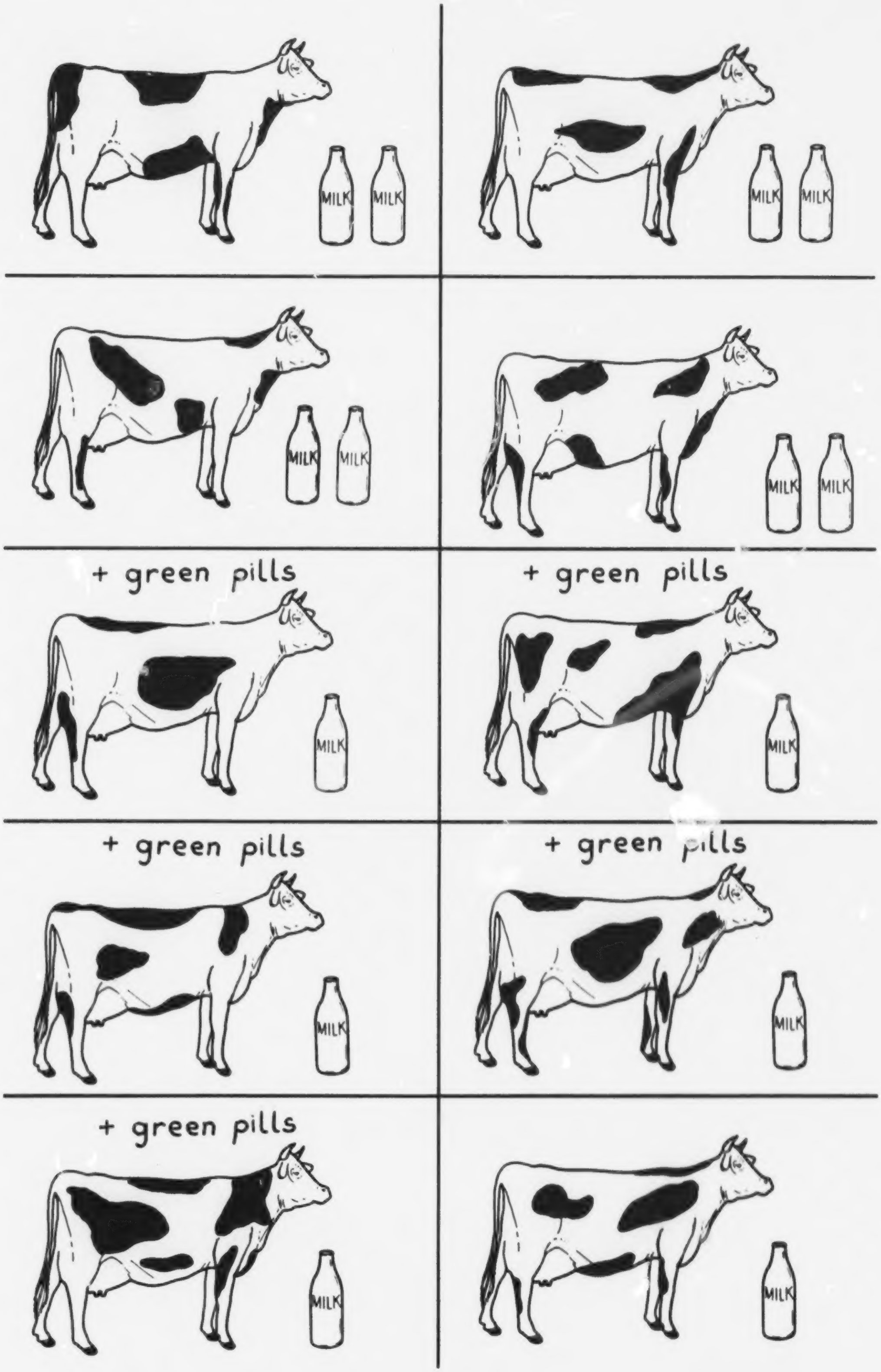
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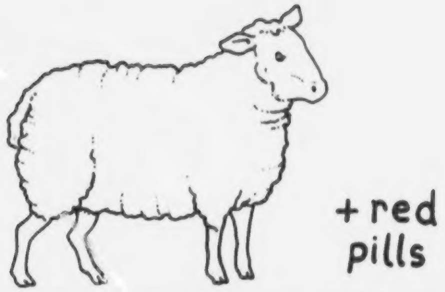
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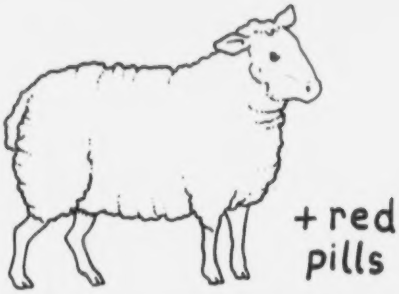
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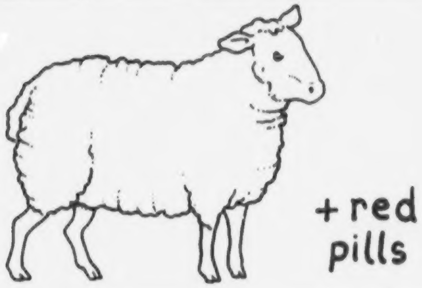
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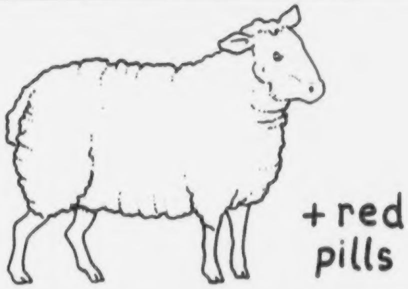
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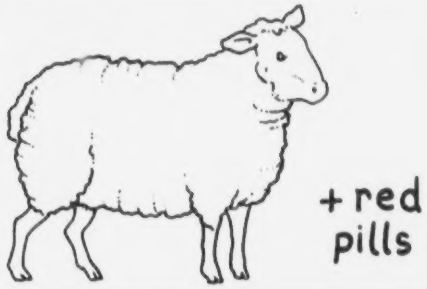
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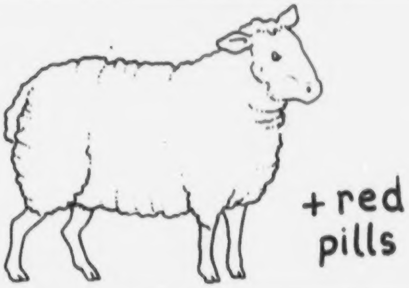
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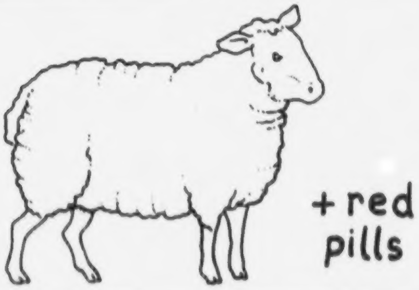
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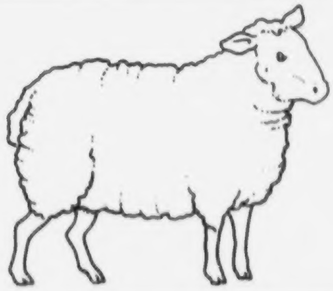
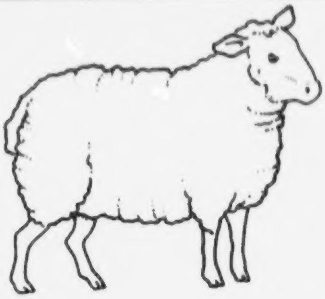
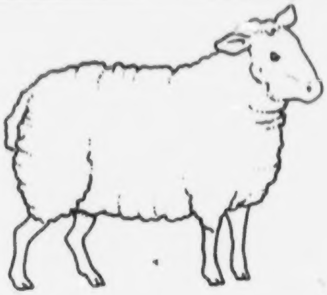
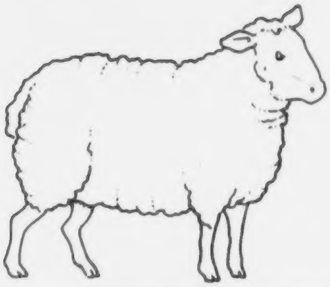
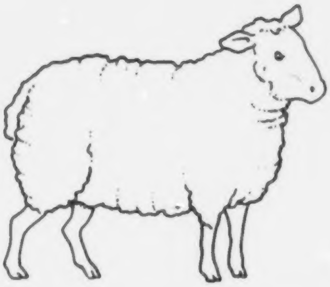
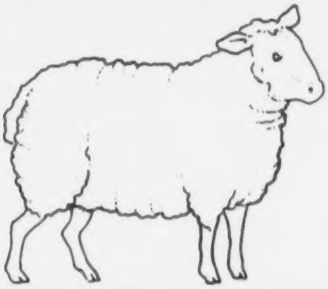


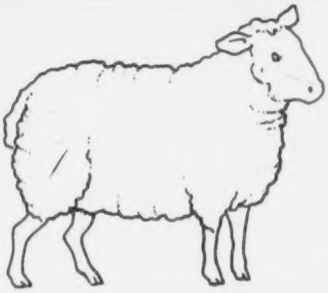


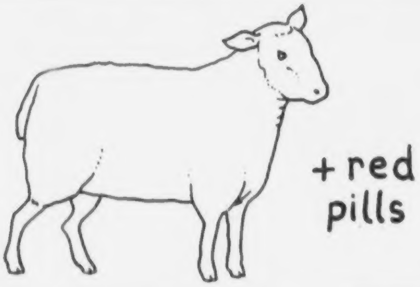


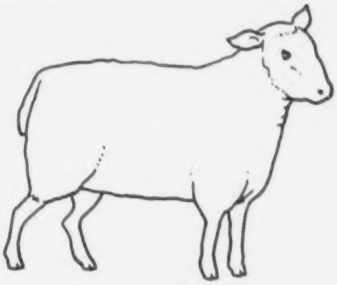


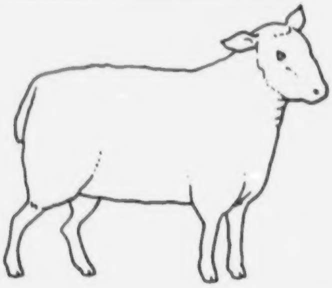


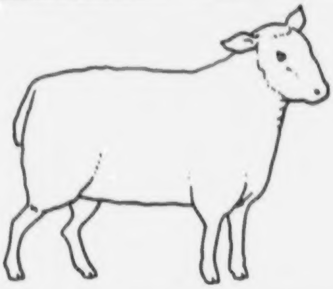


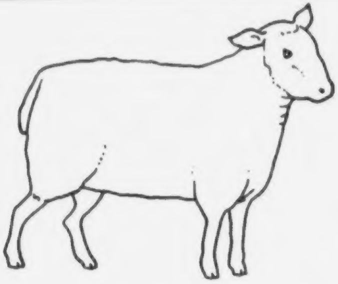


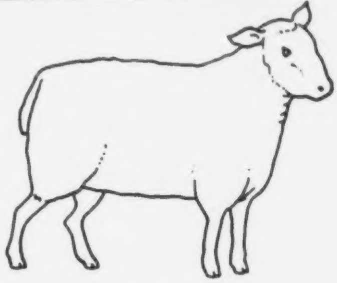

+ red
pills











Activity 18: Example Card A
Treatments and effects

Professor Boffin's results

	Treatment with Grocaro	**No treatment** without Grocaro
Effect bigger carrots	A 17	B 1
No effect usual size carrots	C 3	D 19

Professor Brainbox's results

	Treatment with Grocaro	**No treatment** without Grocaro
Effect bigger carrots	A 12	B 8
No effect usual size carrots	C 8	D 12

Correlation

1 If you have more animals or plants that prove the treatment works than ones that do not prove the treatment works, then you have a

POSITIVE CORRELATION

2 If you have more animals or plants that disprove the treatment than ones that prove it, then you have a

NEGATIVE CORRELATION

3 If you have the same number of animals or plants that prove the treatment works as ones that disprove it, then you have

NO CORRELATION

Activity 18: Example Card B
Treatments and effects

Results from each group's cards

	Treatment (T) and Effect (E)				
Examples	A +T, +E	B −T, +E	C +T, −E	D −T, −E	**Correlation** A+D:B+C
carrots/Grocaro					
● Professor Boffin	17	1	3	19	36:4
● Professor Brainbox	12	8	8	12	24:16 positive
sheep/red pills					
cows/green pills					
pigs/brown pills					
wheat/fertiliser					
roses/leaf shine					

Activity 19: Sampling: fish in a pond

Introduction

Sampling is an important aspect of science, particularly biology. The representativeness of a sample is discussed and a pencil and paper exercise in random sampling is provided. This also provides a further example of proportionality. Temperature charts for holiday resorts are used to illustrate the 'collapse' of samples to give average values. They also give students experience in reading graphical data.

Apparatus summary

Per group

- About 500 melon seeds in bag, marker pen
- Workcard

Per pupil

- Worksheet

Procedure summary

1 Introduce sampling: e.g. dipping a toe in water before jumping in. Sampling is 'Choosing a part to represent the whole so that predictions can be made'. How can samples be made representative? The idea of random sampling.

2 Questions in the first section of the Worksheet are for discussion. The melon seed exercise models capture/recapture. Keep making the links between the melon seed model and the fish pond reality. The proportionality problem is quite difficult. Section 5 focuses discussion on notions of sampling and random distribution.

3 Pupils use the Workcard data on temperature and hours of sunshine in holiday resorts to **answer questions. Variables** include month (or time of year), average daily temperature, and hours of sunshine.

4 Finally, how representative are samples? From the temperature **charts,**can you be sure that the maximum temperature in Corfu in September is going to be 82°C every day? Consider other examples such as opinion polls, using a telephone directory to find people to ask who they'll vote for, picking the first five students who leave school on a Friday afternoon to represent the whole school's attitude to wearing school uniform etc.

Procedure details

1 Introduce the notion of a sample by referring to everyday examples such as dipping a toe in water before jumping in, testing a cake to see if it is baked, and opinion polls. Define it as 'Choosing a part to represent the whole, so that predictions can be made'. Ask for ideas about how to make samples representative. Introduce the term **random sampling**.

2 Start on the 'How many fish in a pond' problem. Worksheet section 1 questions are for discussion. The melon seed exercise is a model of the **capture/recapture** method. Shaking the bag represents the free movement of the animals, and taking handfuls represents random sampling. Keep making the links between the model, melon seeds, and reality, the fish pond.

The proportionality problem is quite difficult. Try rewording it in different ways, but in the end many may have to resort to the concrete use of the algorithm and a calculator.

There are no 'right' answers to the questions in section 5. Use them to emphasise important notions in sampling – the bigger the sample the better, and random distribution.

These notes about the capture/recapture method of sampling organisms are for your background information:

- the marks must not have an effect on the animal – for instance, making it more susceptable to predation;
- the animal must be free to move over the whole sample area;
- collecting, counting, and releasing should be as fast as possible;
- the interval between release and recapture is important – for instance, snails would take longer to disperse than deer or fish;
- accuracy is affected by birth and death rates, and by immigration into and emigration from the sample area.

3 For the second exercise, **refer to the data on** temperature and hours of sunshine in holiday resorts. Pupils use the charts to answer **the Worksheet** questions. Variables include month (or time of year), average daily temperature, and hours of sunshine. The values are, for instance, April–October; 55–95°C; 6–12 hours, respectively.

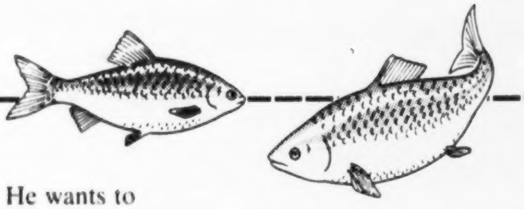
4 A final question for discussion is how representative are samples? From the temperature charts can you be sure that the maximum temperature in Corfu in September is going to be 82°C every day? Consider other examples such as opinion polls, using a telephone directory to find people to ask who they'll vote for, picking the first five students who leave school on a Friday afternoon to represent the whole school's attitude to wearing school uniform etc.

Your name: ....

Activity 19: Worksheet Sampling

Probability

How many fish in a pond?



1 The problem

A fish farmer has fish in a pond. He wants to count his fish population.

Think about these questions:

- What does 'population' mean here?
- How might he try and find out how many fish there are?
- What sort of problems might he have?

2 A model

Here is one way to estimate the number of animals in a population.

Melon seeds in a bag can be used to model fish in a pond.

What do the seeds represent? ....

What does the bag represent? ....

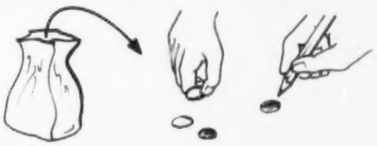
If you pull out a handful of seeds, what does that represent? ....

....

What does shaking the bag up represent? ....

....

3 Trying it



Take out three handfuls of seeds. This is your first sample. Count them and mark them.

The number of seeds in your first sample, $A =$ ....

Put them all back in the bag and shake it up well.
Take out another three handfuls.
Count the number of seeds in this sample, and how many of the seeds are marked.

Second sample: total in sample $Y =$ ....
marked seeds $X =$ ....

Your name: ....

4 *Working it out*

Each time you take a sample, you take a *proportion* of the total number of seeds – maybe $\frac{1}{3}$, maybe $\frac{1}{10}$, you don't know.

Suppose the total number of seeds in the bag is N. If the number in your first sample is A, then the proportion of the total that you took was A/N.

Your second sample is representative of the whole population. The proportion of marked seeds will show you the proportion that you took out the first time.

the proportion of marked seeds in the second sample	*is the same as*	the proportion of number of seeds in the first sample to the total number of seeds
$X:Y$	$=$	$A:N$

You know X, Y, and A because you have counted them. Find N, the total population, by putting in your figures for X, Y and A:

$$\text{The estimated population, } N = \frac{\ldots\ldots\ldots\ (Y)}{\ldots\ldots\ldots\ (X)} \times \ldots\ldots\ldots\ (A) = \ldots\ldots\ldots$$

5 *Checking*

Now see how accurate your estimate is.
Empty out all the seeds and count them.

The total number of seeds is ....

Was your estimate close to the real number? ....

Do you think this is a good way to estimate a population of animals? Explain why you think so.

....

....

Can you think of a way to estimate the size of a flower population – for example the number of daisies in a field?

....

....

....

▶

Your name: ....

Average temperatures

A holiday brochure describes the climate in three holiday resorts. For each resort it gives:

- the average daily maximum temperature, and
- the hours of sunshine.

What are the variables? ....

What are their values? ....

....

To which of the three resorts would you go if you wanted the hottest October? ....

Where and in what month would you get most hours of sunshine? ....

What is the variation in average maximum temperature for London from April to October?

lowest: .... to highest: ....

Which of the three resorts has the most variable maximum temperature from April to October? ....

How do you think that the average daily temperature for one month is found? Discuss with your group or with your teacher before answering.

....

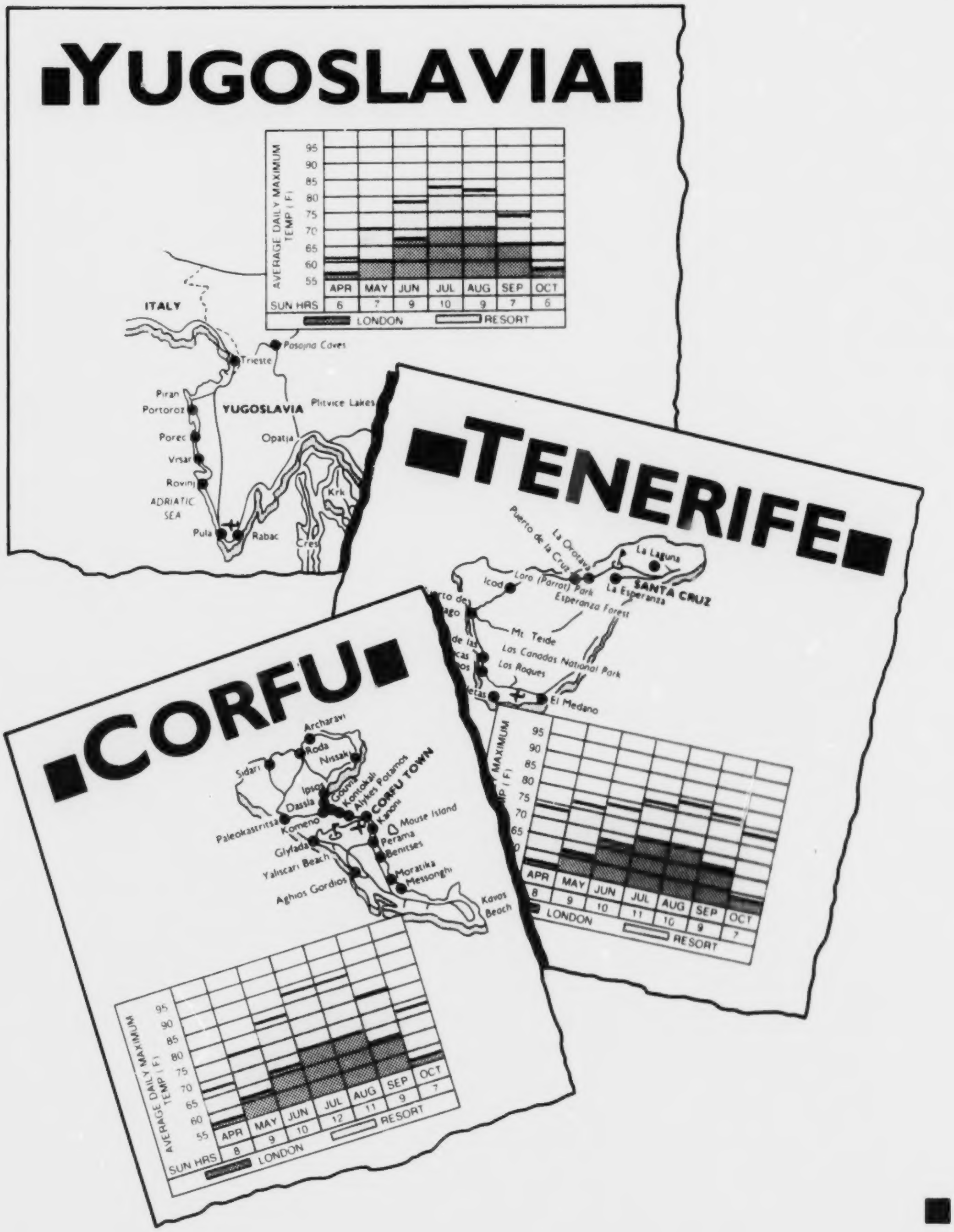
....

....

....

Activity 19: Workcard Sampling

Probability



Activity 20: Throwing dice

Introduction

This is the last activity on probability. There are no new concepts, but those introduced in previous activities are formalised and consolidated. Throwing dice and processing the results provides a concrete expression of the idea that the probability of something happening is the ratio of the number of possible ways that it can happen to the total number of events.

Apparatus summary

Per group

- A pair of dice, different colours e.g. red and green

Per pupil

- Worksheet
- Example Card

Procedure summary

1 Can you predict what number you will get when dice are thrown? 'Probability' is the word used for the mathematical expression of 'chance'. 'A probability of 1 in 10' means that over a large number of times, the event will occur once in ten times.

2 Refer to the Worksheet and the pairs of dice. Demonstrate with the Example Card and explain how the table is to be complete.

3 Pupils add up the rows and columns, and check that the total is exactly 36. Then they can answer the first four questions on the **Worksheet section 3 for their own throws and those of three other groups.**

4 Each group adds their results to the Example Card table. The average number of times out of 36 that each event occurs should approach 6, 6, 3, and 16 respectively.

5 Use the complete Example Card table to highlight the boxes that represent the different ways that you can get a total of, say 5 (R1/G4, R2/G3, R3/G2, R4/G1). Pupils work out the probability of getting any particular total.

6 The probability of something happening is the number of possible ways it can happen, divided by all of the possibilities. Give more examples using dice and cards. Recap probability problems encountered in previous activities.

Procedure details

1 Introduce the topic as an investigation into the possibility of predicting what number(s) you will get when a pair of dice are thrown. You could leave a question such as 'is the probability of getting 10 the same as that of getting 6?' as an open start to the investigation. Emphasise again that 'probability' is the word used for the mathematical expression of 'chance'. We talk, for instance, of 'a probability of one in ten' meaning that over a large number of times, the event will occur once in ten times. In a limited experiment, the actual number of times it happens in ten throws will vary randomly.

2 Refer to the Worksheet and the pairs of dice. Demonstrate with the Example Card and explain how the table is to be complete, with a tally mark in the box corresponding to the numbers on the red and green dice for each throw. Let them get on with it, going around to check that they are completing the table correctly.

3 When they finish, they should add up the rows and columns, and check that the total is exactly 36. Then they can answer the questions on the Worksheet section 3 for their own results, and after consultation with two other groups, complete the second column also. Note that this should be the *average* number for three groups so if, say, the number of times the red die was 6 with three groups was 7, 4, and 6, then the average to be entered is 5⅔ or 5.67

4 Each group can also add their results to a table like this on the board or Example Card:

	Group					No. of	
	1	2	3	5 . . . *n*	Total	groups	Average
Red die a 6:							
Green die a 6:							
Total 10:							
Either die, or total = 6:							

When each group has put in their results, add and divide by the number of groups to get the average number of times out of 36 that each event has occurred. They should approach 6, 6, 3, and 16 respectively.

5 To help pupils answer the problems, use **the Example Card table and** highlight the boxes that represent the different ways that you can get a total of, say, 5 (R1/G4, R2/G3, R3/G2, R4/G1). Once they have this idea, they should be able to work out how many ways there are of getting any particular total and expressing this as a probability out of a total of 36 different possible combinations. In this example the chance of getting a 5 is 4/36.

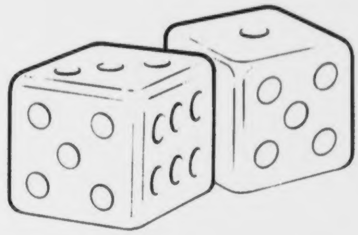
6 Conclude the lesson by emphasising that the probability of something happening is the number of possible ways it can happen, divided by all of the possibilities. In the case of two dice of different colours, the total number of possibilities is 36. One possible activity would be for pupils to sketch 6×6 tables and colour in or otherwise mark the boxes corresponding to particular sums or combinations from, for instance, 'both dice 5s' (1 box) to 'either dice 5 or sum 5' (15 boxes).

In a pack of cards, the number of possibilities is 52. If you have time, you can set problems such as 'what is the probability of picking a heart? (13/52 = 1/4). '. . . of picking a jack?' and so on. You could also look back to the combinations and to the tea tasting interventions. What are all the possible combinations of milk first/milk last in five cups of tea? (1+5+10+10+5+1=32); and how many ways can you get four right or five right? (5+1=6); so the probability of getting four or five right just by guessing is 6 in 32, nearly one fifth.

Your name: ....

Activity 20: Worksheet Throwing dice

Probability



When you throw a pair of dice, you cannot **predict** what numbers will come up.

But you can work out the **probability** of getting a number you want.

The variables are:

the total number of times you throw the dice, and the number of times you get a particular number.

1 Collecting data

Throw the pair of dice *exactly 36 times.*

Record every result in this table: put a tally mark in one box for every throw, e.g. if the red is 3 and the green is 1, put a mark in the third box along the first row.

Red die

Green die	1	2	3	4	5	6	Totals
1							
2							
3							
4							
5							
6							
Totals							Grand total

2 Checking

Add up the totals of the rows.
Add up the totals of the columns.
Check that the grand total is 36.

Your name: ....

3 *Summarising*

Under the column headed 'Yours', answer the following questions from your results:

	Yours	Average of three groups	Average of whole class
1 How many times was the red die a 6?	....	....	....
2 How many times was the green die a 6?	....	....	....
3 How many times was the sum of the red die and the green die 10?	....	....	....
4 How many times was *either* the red die a 6, *or* the green die a 6, *or* the sum of red die and green die 6?	....	....	....

Now, ask two other groups for their answers to the same questions. Find the average of your three groups' results, and fill in the second column of the table.

Your teacher will collect the results for the whole class. Put them in the last column of your table.

4 *Problems*

1 How many different ways are there of getting a total of 8? (Count the squares in the table in section 1 where the sum is 8, e.g. red 2, green 4; red 3, green 5; and so on.) ....

2 From the class results, what was the *probability* (out of 36 throws) of the sum of red and green die being 10? ....

3 How many different ways (out of 36 possibilities) are there of getting a total of 10? ....

4 So in general, what is the probability (out of 36) of getting a total of 10? ....

5 How does this compare to your class result? ....

6 If it is not the same, why do you think it is different?

....

7 In the game of backgammon, you can move a piece ten places if the total of both dice is 10. You can move a piece six places if either of the dice has a six on it, or if the total of both dice is 6. How many times greater is the chance of moving a piece six places than the chance of moving it ten places?

....

....

Activity 20: Example Card
Throwing dice

Red die

Green die

	1	2	3	4	5	6	Totals
1							
2							
3							
4							
5							
6							
Totals							Grand total

Activity 21: Making groups

Classification

Introduction

Much curriculum work for this age teaches setting: dividing things into smaller and smaller groups. Actually, there is no one mental strategy for classifying things in a formal way. Classification involves firstly determining the goal of a particular classification. This determines what characteristics are chosen. If these prove not to be adequate for the purpose, new criteria must be applied. Each activity in this lesson highlights a different aspect of classification and encourages the use of problem solving strategies. Flexibility and an understanding of the open nature of problems is encouraged. The important words are **classify** and **characteristic**.

Apparatus summary

Per group

- Eight test tubes containing substances which are coloured or colourless; soluble or insoluble
- Workcard A 'Creepy crawlies'
- Workcard B 'Big animals'

One or two sets

- Selection of tins, jars, and packets from larder (for "store cupboard" activity)

Per pupil

- Worksheet

Procedure summary

Activity 1 should done first and 6 last. All activities are on the Worksheet

1 *Living and non-living things* Pupils compare their lists to become conscious of their own sorting strategies. Many of the accepted characteristics of living things will arise naturally.

2 *'Creepy crawlies'* The emphasis should be on the identification of characteristics which are useful. Similarities include jointed legs, antennae. Differences are numbers of legs, number of body segments, patterns on the body, wings, etc.**(Workcard A)**

3 *Chemicals* Classification relies on appearance and on solubility. A 2×2 table allows the use of two differences at once.

4 *Store cupboard* Characteristics chosen depend on perceptions of a useful sorting method. Labelling shelves makes characteristics explicit. Classification is only useful if it simplifies the situation. Pupils should think why this is difficult.

5 *Big animals* Useful characteristics arise from the drawings, from what is known about habitats or diets, or from what is written. Selected characteristics must be applied consistently.**(Workcard B)**

6 *Thinking back* This highlights what makes classifying some things easier than others.

Procedure details

The order of activities does not matter except that 1, Living and non-living things, should be done first by everyone and 6, Thinking back, must be done last. You may have to manage the class to give access to the 'store cupboard' (4) in rotation.

1 *Living and non-living things* You may tell the pupils that there are 13 living things in the list. Encourage them to compare their lists with others. This helps them to become conscious of their own sorting strategies. After they have had a chance to argue through their own differences of opinion, you can summarise. Incidentally, this activity may highlight misconceptions which individual children have which could be followed up later.

There need be no presentation of the seven accepted characteristics of living things. Many will arise naturally from the children's discussion. The aim is not to teach these but to highlight how sorting things depends on choosing characteristics and then looking for their presence or absence in everything. The final problem introduces pupils to class inclusion and will be followed up in Activity 22.

2 *'Creepy crawlies'* The pictures show nine anthropods, drawn to scale (this need not be made explicit, but could link to previous work on scaling). It is helpful to say that in real life, the animals towards the bottom of the page are smaller.**(Workcard A)**

The emphasis should not be on the biological characteristics of these groups, but on the ability to identify any characteristics which are useful in classifying. Similarities include jointed legs, antennae, or any other feature which belongs to all members of the group. Differences are numbers of legs, number of body segments, patterns on the body, wings, etc.

3 *Chemicals* Here the classification relies both on visual characteristics (coloured or white) and on a functional property (solubility). These two characteristics are used simultaneously to set and subset. A 2×2 table encourages the use of the two differences simultaneously, making four groups. This is similar to the strategy used in the correlation activities.

4 *Store cupboard* This presents pupils with a real situation where classification is useful. Characteristics chosen depend on the pupils' own perception of a useful sorting method. Labelling the shelves forces them to make their characteristics explicit. There should be discussion and argument about the 'best' way to arrange things in the store cupboard. If there are too many subsets for the number of shelves, the point is made that a classification is only useful if it simplifies the situation. To be easily classifiable, objects should have a number of common features. Pupils should have confidence in a situation which has no right answer, and they can leave the activity incomplete provided they have thought about why it is difficult.

5 *Big animals* Once again it is not important that pupils learn correct biological criteria for classifying. They should look for useful characteristics from the drawings, from what they know about the animal's habitat or diet. Characteristics which are selected must be applied consistently to all of the animals. There are several different solutions to this problem, some better than others because they use more observable characteristics or would serve a more useful purpose. **(Workcard B)**

This is a discussion and extension activity, and no space is left for written answers, although these could be done as homework.

6 *Thinking back* Use the pupils' answers to questions at the end of each exercise to highlight what makes classifying some things easier than others. Some points that may be raised are:

- Familiar things are generally easier to classify than unfamiliar ones. In science many things are unfamiliar.
- Visible characteristics tend to be easier to use but sometimes it is more useful to use functions or more abstract characteristics, such as habitats of animals, or types of reactions of chemicals.
- The selection of characteristics to be used depends on the purpose of the classification.
- Only groups with a number of shared characteristics can be classified into smaller sub-groups with any meaning. Groups of randomly selected items are too different and their classification would be too complex to be useful.
- A 2×2 table helps to classify a group of similar things into four using just two differences.

Your name: ....

Activity 21: Worksheet
Making groups

Classification

1 Living and non-living

Here is a list of living and non-living things. Put a tick by everything you think is *living*.

car ....
cloud ....
bird ....
fish ....
insect ....
planet ....
wind ....
moss ....
milk ....
seaweed ....
nature ....
snail ....
tree ....
cat ....
human ....
book ....
grass ....
rose ....
energy ....
rain ....
tulip ....
fox ....
fire ....
water ....

What made *you* decide what was living? ....

....

Are there more animals or more living things? ....

2 'Creepy crawlies'

Look at the page of pictures of 'Creepy crawlies'. Spot two characteristics that they all share. **(Workcard A)**

They all look the same because:

1 .... 2 ....

List at least *four* characteristics you can see that are different.

1 .... 2 ....
3 .... 4 ....

▶

Your name: ....

a

Use one of these characteristics to make two groups:

Group 1 (numbers):		These all have ....
Group 2 (numbers):		These all *do not* have ....

b

Now divide all the animals into two *different* groups, using another one of the characteristic differences.

Group 3 (numbers):		These all have ....
Group 4 (numbers):		These all *do not* have ....

c

Use both characteristics at the same time to make four groups of animals.

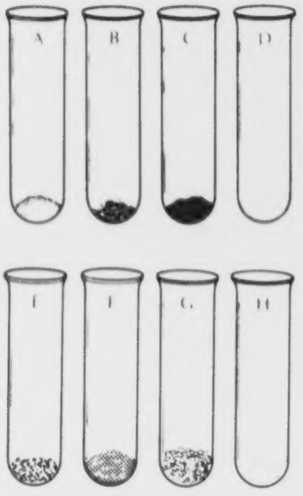
	Characteristic 1 Group 1, all have	Group 2, all do not have ....
Characteristic 2 Group 3, all have		
Group 4, all do not have		

▶

Your name: ....

3 *Chemicals*

There are eight chemicals in the test tubes A to H.



a

Divide the chemicals into *two* groups, using their appearance.

Group	Chemicals (letters)	Appearance characteristic
1:		
2:		

b

Take a very small amout of each chemical in turn and shake it with water. If the solid disappears, and the liquid is left clear, that chemical is **soluble**. If the liquid is still cloudy, that chemical is **insoluble**.

Divide the chemicals into *two* groups, using their solubility.

Group	Chemicals (letters)	Solubility characteristic
3:		
4:		

c

Now use both differences together to divide the chemicals in *four* groups.

Write the appearance characteristic here →	Group 1	Group 2 ....
Group 3 soluble		
Group 4 insoluble		

▶

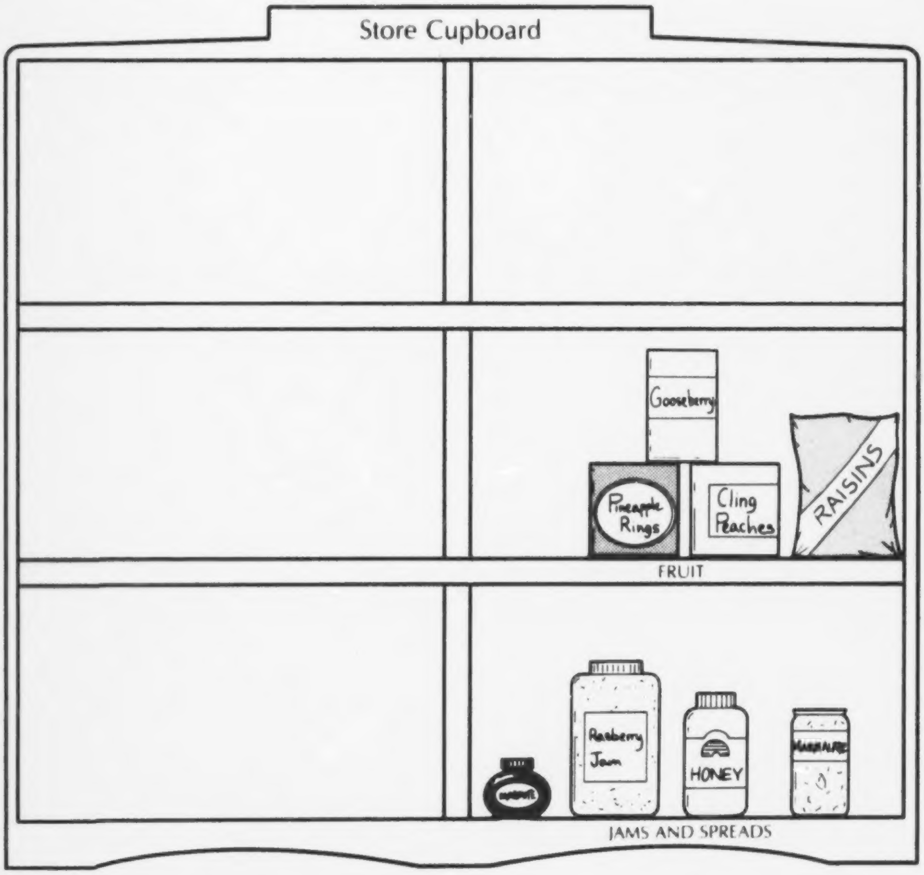
Your name: ....

4 Store cupboard

Look at the selection of tins and packets. Sort them out so that you can store them on the 'shelves' on the drawing of the cupboard.

Write a *label* for each shelf which says what the characteristics of the tins on that shelf are.

Write or draw the tins and packets on their right 'shelf'.


Store Cupboard
Gooseberry
Pineapple Rings
Cling Peaches
RAISINS
FRUIT
Rasberry Jam
HONEY
JAMS AND SPREADS

Which things were particularly difficult to classify?
Where would you put them? Why?

....

....

....

Have other groups used the same classification system as you? Think of why they may or may not have used the same system.

Your name: ....

5 *Big animals*

Look at the pictures of big animals. All of these animals share at least one characteristic: they all have **backbones**. **(Workcard B)**

- Sort them into three or four groups.
- Each group must have at least two animals.
- The members of a group must share at least one characteristic.
- Each group must be different from every other group.

Look at some other groups' classifications.

Are they the same as yours?
In what way are they the same?
In what way are they different?
Are they better than yours? Why do you think they are/are not?

6 *Thinking back*

Put a tick by the classification activity you found easiest.
Put a cross by the one you found most difficult.

1 Living and non-living things ......
2 Creepy crawlies ......
3 Chemicals ......
4 Store cupboard ......
5 Big animals ......

Why was the one you ticked the easiest?

....

Why was the one you marked with a cross the hardest?

....

....

Has everyone ticked and crossed the same things as you?

....

....

Write a sentence about a friend, using the word *characteristic*.

....

....

Why do you think that it is useful to be able to classify things?

....

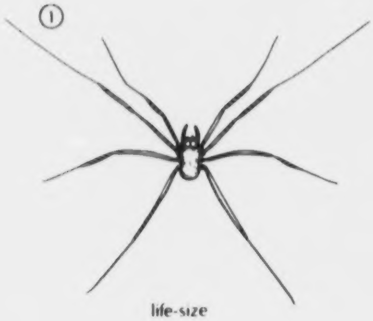
....

Activity 21: Workcard A Making groups

Classification

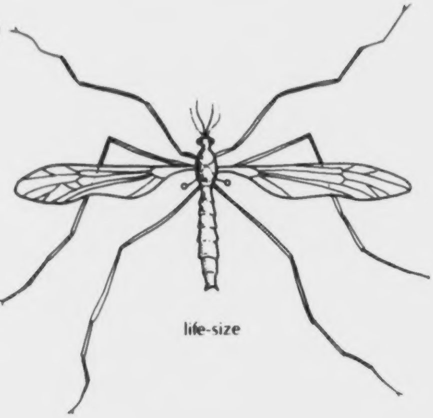
Creepy crawlies

①



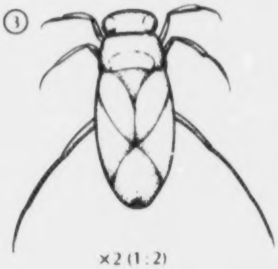
life-size

②



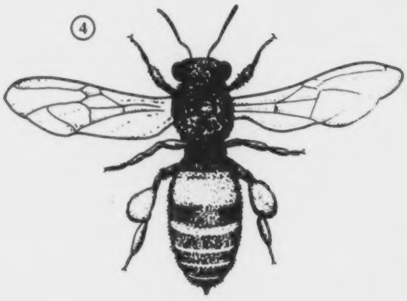
life-size

③



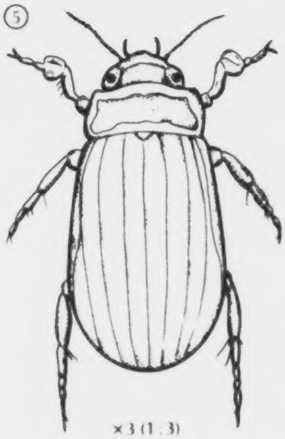
×2 (1:2)

④



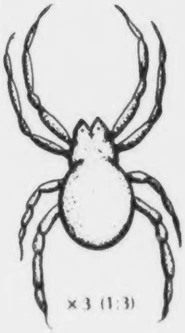
×2 (1:2)

⑤



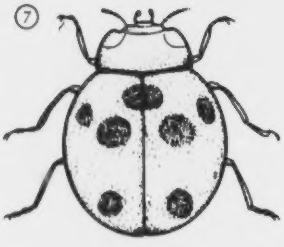
×3 (1:3)

⑥



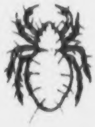
×3 (1:3)

⑦



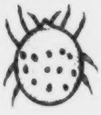
×5 (1:5)

⑧



×10 (1:10)

⑨



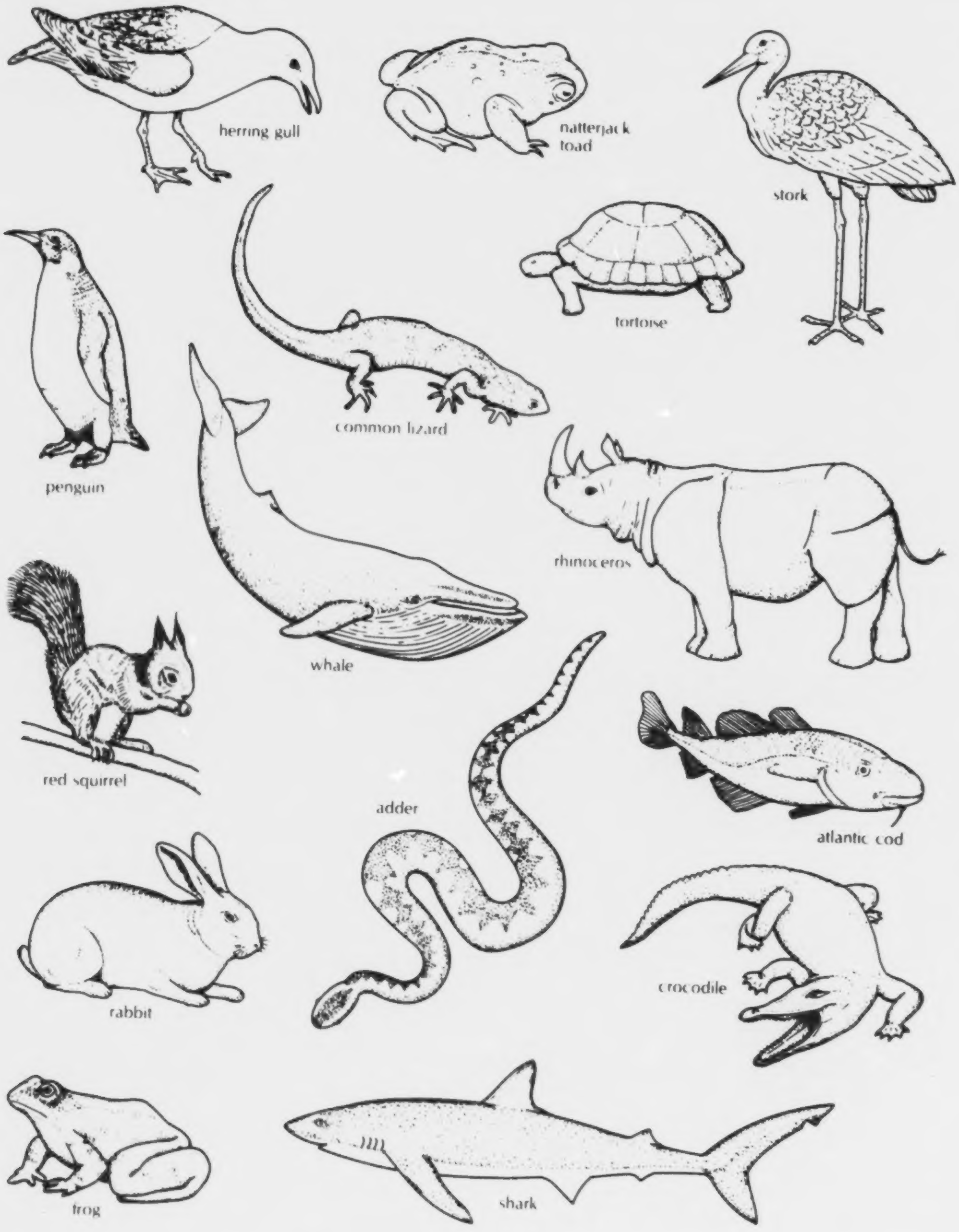
× 10 (1:10)

▶

Activity 21: Workcard B
Making groups

Classification

Big animals


herring gull
natterjack toad
stork
tortoise
penguin
common lizard
rhinoceros
whale
red squirrel
adder
atlantic cod
rabbit
crocodile
frog
shark

Activity 22: More classifying: birds

Introduction

This classification exercise is more complex and open ended than the last. It is introduced by an apparently simple activity on counting animals, which actually consolidates concepts of class inclusion, and the meaning of 'animal'.

Apparatus summary

Per group

- Pictures of animals; set of 20 bird pictures
- Workcards A and B

Per pupil

- Worksheet

Procedure summary

1 There are 30 animals in the Workcard A picture. Sometimes pupils do not count the human, and tend to omit the insects. Questions in Worksheet section 1 require class inclusion and 'thinking in the negative'.

2 Refer to the Workcard B bird pictures. Have pupils cover and not consider the last picture, humming bird,until so instructed. The word classification is the linguistic 'handle' to these activities. Question 3 allows them to focus on visible features. Most pupils will choose a different four. Wide diversity in appearence makes it difficult to classify them.

3 They try sorting birds by size and find that it is not a useful characteristic. One person's small might be another's medium.

4 The difference between sorting and classifying is the use of additional information interesting to those wishing to study birds. Draw pupils' attention to the differences in habitat and food. They try to amalgamate the two sorts of list, looking for sub-categories. The exercise is very open-ended.

5 If time, uncover the humming bird and ask them to put this into their system. A bird from outside the group used to make the initial classification system cannot be classified easily.

6 The last section could be set as homework.

Procedure details

1 Most pupils will find this grouping and sub-grouping straightforward, since the groups are given. There are 30 animals in the Workcard A picture. Sometimes pupils do not count the human, and if they tend to omit the insects, ask them 'are they plants?' If they are not plants, and they are living, they must be animals. The questions are a little trickier in that they require class inclusion and the ability to 'think in the negative' to realise that one animal can exist in two groups at the same time when one of the groups is a subset of the other.

2 Refer to the Workcard B bird pictures (exclude the humming bird). Question 1 simply reminds the pupils of the word classification which is the linguistic 'handle' to these activities, and question 2 provides the word ornithologist which is not important and merely there for interest. Question 3 allows them to focus on visible features. There are so many that most pupils will have chosen a different four. Discussion at this point shows that the wide diversity in appearance of the birds would not make it easy to classify them on the way they look. The additional information next to each bird is not directly observable from the pictures. Ask how one could find out these sorts of facts.

3 Pupils are then asked to sort birds by size. This leads to the discovery that size is not a useful characteristic, since one person's 'small' might be another's 'medium'. The pupils in groups will have to reach a consensus about their categorisation. As they work, act 'the devil's advocate' and make sure they remain uneasy about their judgements of size.

4 What differentiates sorting from classifying is the use of additional information that proves to be 'interesting' to those wishing to study birds. Sorting would use only physical appearance and would not yield useful categories to distinguish one group from another. Draw pupils' attention to the birds' habitats. Encourage them to make a list of all the birds found near fresh water or sea shores, on moorland, in woods . . . then turn their attention to food. List all those which eat live meat, only vegetation, dead meat, shell fish, fish . . . They can then try to amalgamate the two sorts of list, looking for sub-categories. This is a formal exercise and could take time.

The exercise is very open-ended and this may worry some pupils. They should be made to feel that their attempts are as valid as any 'proper' system, provided there is an underlying logic to their groupings and they can clearly state what distinguishes one group from another. For those that really cannot cope, give them a smaller number of birds with very clear distinguishing features to classify, perhaps all those that eat fish, those that live in woods etc. You can also refer them back to the first questions, which will remind them of how they sub-divided large groups.

5 If they are getting on well and there is time, you can refer to the last picture, the humming bird, and ask them to put this into their classification system. The question point out that a bird from well outside the group used to make the initial classification system cannot be classified easily, and a new system must be set up. The other 20 birds have one common feature, they are all native to Britain. The humming bird is not. The new system would have to include birds worldwide.

6 The last Worksheet activity could be set as homework. It is to make the point that classifying is an important part of everyday life.

Your name: ....

Activity 22: Worksheet More classifying: birds

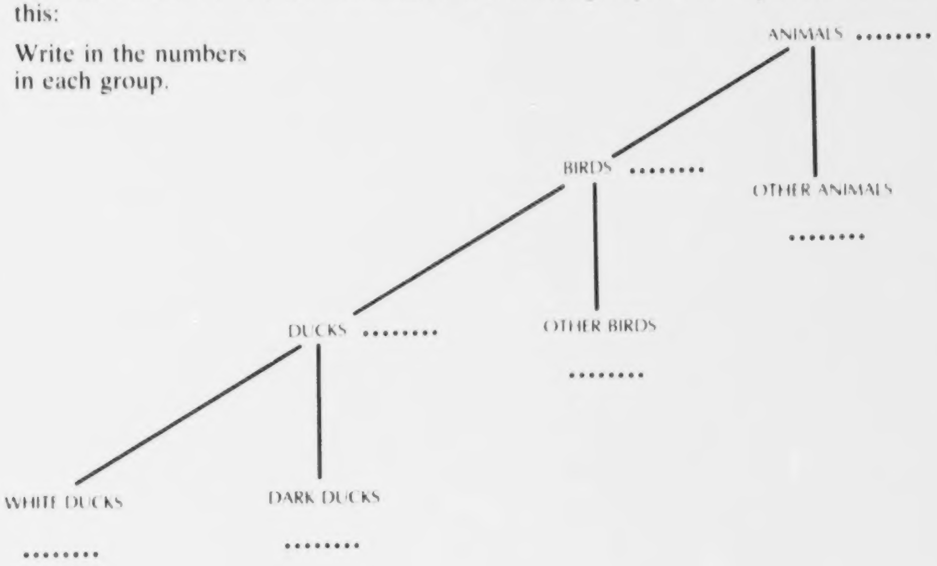
Classification

1 Count the animals

There are several animals in the picture (Workcard A). Can you spot them all? Remember that the living world is divided into *plants* and *animals*.

The animals can be divided into smaller and smaller groups. One way could be like this:

Write in the numbers in each group.



Now answer these questions:

1 How many birds are there? ....

2 Are there more birds or more animals? ....

3 How many animals are not birds? ....

4 How many animals are not ducks? ....

5 How many animals are not dark ducks? ....

6 Are there more animals that are not birds or more animals that are not ducks? ....

(*Hint* What would be left if all the ducks were shot by a hunter? What would be left if all the birds were killed?)

Your name: ....

2 *Characteristics of birds*

Four hundred and fifty different types of birds have been officially recorded in Britain. About 200 of these are quite common. To make it easier to study so many types, they must be sorted into groups.

1 What do we call this sorting process? ....

2 What do we call someone who studies birds? ....

See if you can help ornithologists by making a classification system. Look at the 20 pictures of **birds on Workcard B**

3 List *four* characteristics you can see which you might use.

A .... B ....

C .... D ....

3 *Size*

Use the *size* of the birds to sort them into three groups.
Write the names of the birds in three groups in this table:

Small birds	Medium birds	Large birds

1 How did you decide which were small birds and which were large?

....

2 Look at your list of birds in each group. It is not very useful for someone interested in birds. Why not?

....

▶

Your name: ....

4 A useful system

1 Look again at all the characteristics of the birds you have discussed. Which do you think are the most *useful* for classifying? (You can give more than one.)

....

2 Why do you think so?

....

Use these characteristics to regroup your birds into a more useful classification. Use blank paper or your notebook.

You should produce a list of the birds in each group, and the characteristics of that group of birds.

5 An odd bird

When you have finished your classification, uncover the picture of the humming bird.

1 Does this fit into any of the groups you have made? ....

2 If it does, which group and why? If it does not, why doesn't it?

....

3 How would you make a bird classification system that the humming bird does fit into?

....

....

6 Classifying at home

In the last two lessons you have done lots of 'sorting out' of different things.

Write down two sorts of things that you or people you know find it useful to classify at home or at work (*not* any of the things you classify in science lessons.)

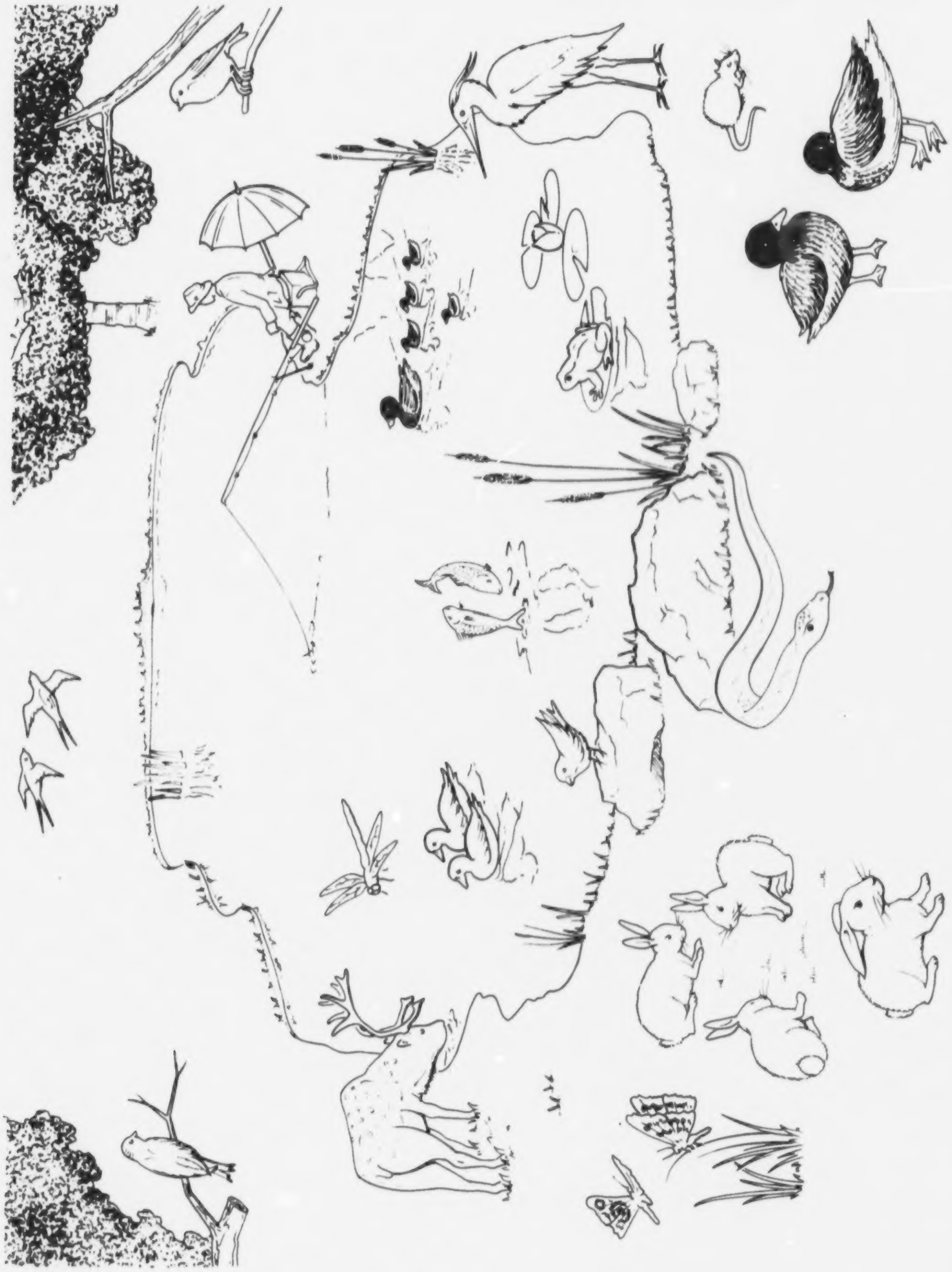
....

....

If you have time, try to devise a classification system for one of these things.

Activity 22: Workcard A
More classifying: birds

Classification



Activity 22: Workcard B

Classification

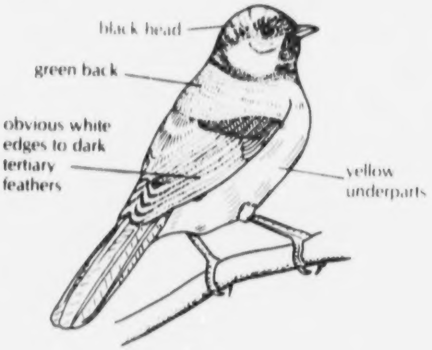
More classifying: birds

Great tit

Size: 5 inches

Lives in: woodland, parks, hedges, gardens

Eats: insects, spiders, nuts, berries, worms, buds

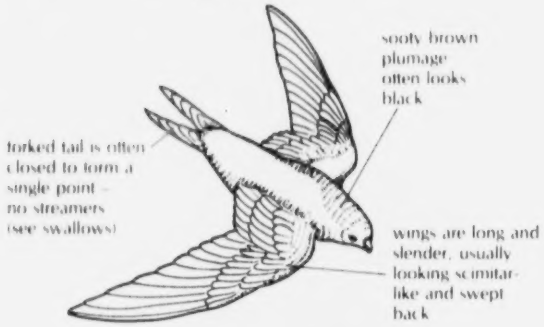

black head
green back
obvious white edges to dark tertiary feathers
yellow underparts

Swift

Size: 6 inches

Lives in: open air near houses, lakes, marshes

Eats: insects in the air

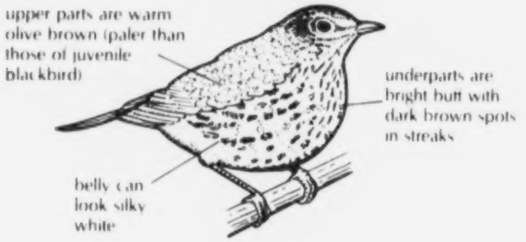

sooty brown plumage often looks black
forked tail is often closed to form a single point – no streamers (see swallows)
wings are long and slender, usually looking scimitar-like and swept back

Song thrush

Size: 9 inches

Lives in: woods, hedges, parks, suburban gardens

Eats: worms, insects, snails

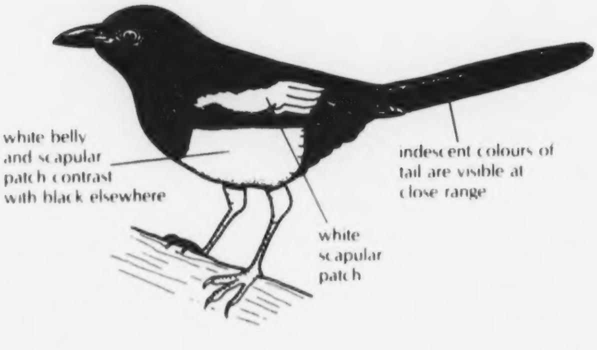

upper parts are warm olive brown (paler than those of juvenile blackbird)
underparts are bright buff with dark brown spots in streaks
belly can look silky white

Magpie

Size: 18 inches

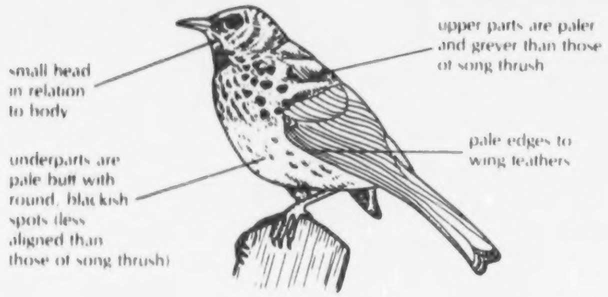
Lives in: woodland, farmland, roadsides

Eats: insects, mice, eggs, scraps of food, seeds


white belly and scapular patch contrast with black elsewhere
indescent colours of tail are visible at close range
white scapular patch

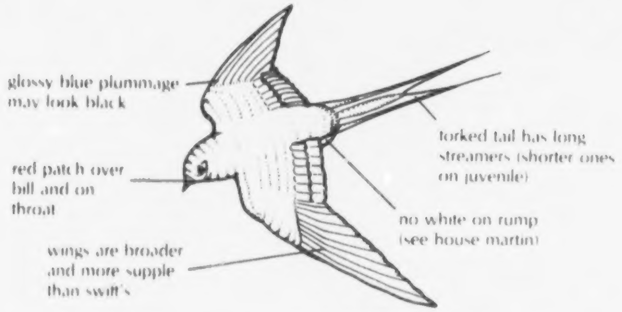
Mistle thrush

Size:	10 inches
Lives in:	woods, moors, parks, farmland
Eats:	worms, insects, snails, berries


small head in relation to body
upper parts are paler and greyer than those of song thrush
pale edges to wing feathers
underparts are pale buff with round, blackish spots (less aligned than those of song thrush)

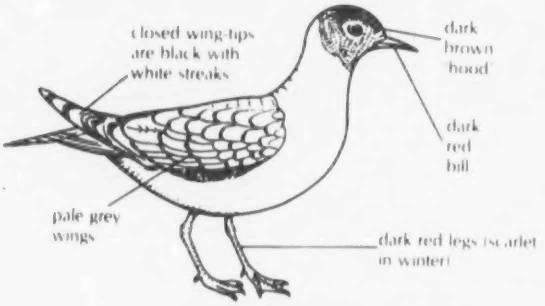
Swallow

Size:	7 inches
Lives in:	open areas near lakes, reservoirs
Eats:	insects in the air


glossy blue plummage may look black
forked tail has long streamers (shorter ones on juvenile)
red patch over bill and on throat
no white on rump (see house martin)
wings are broader and more supple than swift's

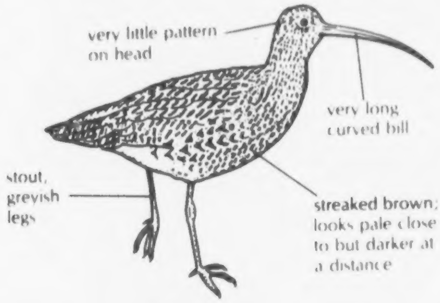
Black headed gull

Size:	15 inches
Lives in:	wet fields, seashore
Eats:	fish, mussels and other shell fish, insects, worms, berries, bread


closed wing-tips are black with white streaks
dark brown 'hood'
dark red bill
pale grey wings
dark red legs (scarlet in winter)

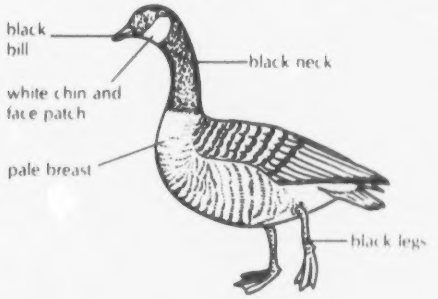
Curlew

Size:	22 inches
Lives in:	moorlands, wet fields, rocky sea shores
Eats:	worms, crabs, small insects


very little pattern on head
very long curved bill
stout, greyish legs
streaked brown; looks pale close to but darker at a distance

Canada goose

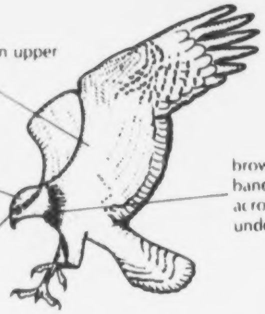
Size:	40 inches
Lives in:	lakes, reservoirs, canals
Eats:	little fish, grazes meadows


black bill
black neck
white chin and face patch
pale breast
black legs

▶

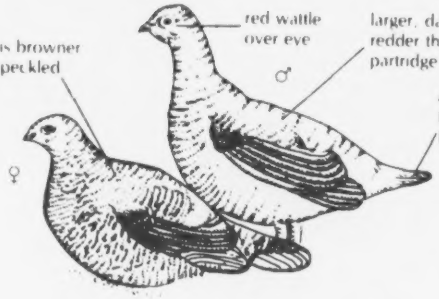
Osprey

Size: 23 inches
Lives in: large lakes, reservoirs, rivers, sheltered coasts
Eats: fish


rich brown upper parts
crested head
brownish band across white underparts
head is whitish with a broad black band

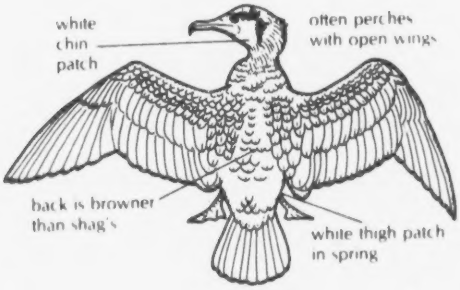
Red grouse

Size: 15 inches
Lives in: open moorland
Eats: young heather shoots, buds, berries


plummage is browner and more speckled than on ♂
red wattle over eye
larger, darker and redder than partridge
♂
obvious blackish-brown tail
♀

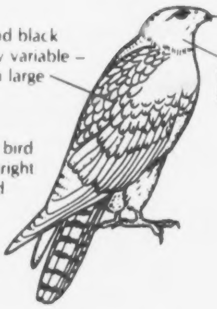
Comorant

Size: 36 inches
Lives in: rivers, lakes, reservoirs, sea shores
Eats: fish


white chin patch
often perches with open wings
back is browner than shag's
white thigh patch in spring

Buzzard

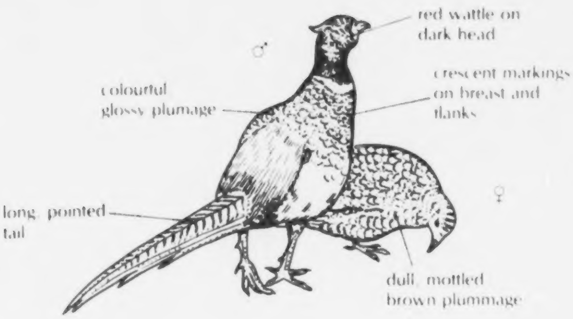
Size: 22 inches
Lives in: woods, hedges
Eats: rabbits, mice, small birds, beetles, worms


brown, cream and black plummage is very variable – may be pale with large areas of cream
stout, hooked bill
rounded head
perched bird looks upright and solid

▶

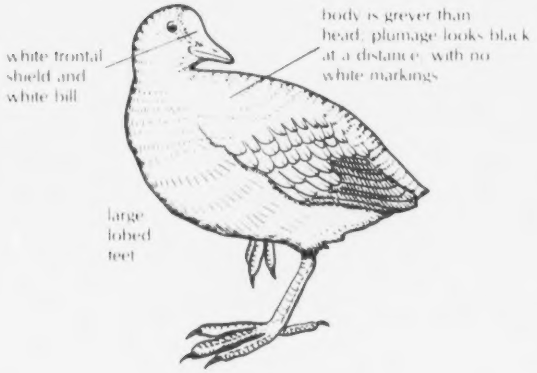
Pheasant

Size: 30 inches
Lives in: woods
Eats: insects, worms, seeds, berries


red wattle on dark head
♂
colourful glossy plumage
crescent markings on breast and flanks
♀
long, pointed tail
dull, mottled brown plummage

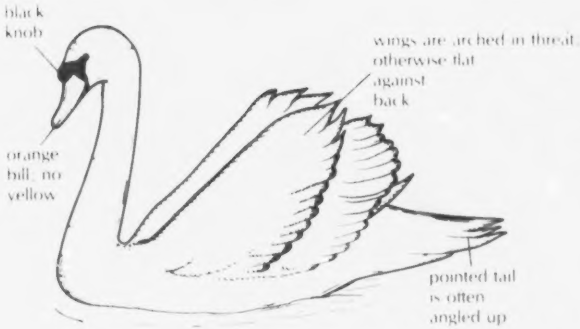
Coot

Size: 15 inches
Lives in: all freshwater
Eats: water weed and small plants


body is greyer than head, plumage looks black at a distance, with no white markings
white frontal shield and white bill
large lobed feet

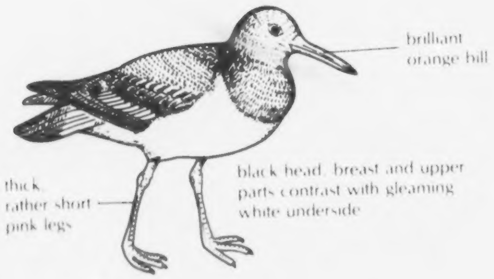
Mute Swan

Size: 60 inches
Lives in: all freshwater and sheltered seashores
Eats: small fish, grazes on grass


black knob
wings are arched in threat, otherwise flat against back
orange bill; no yellow
pointed tail is often angled up

Oyster catcher

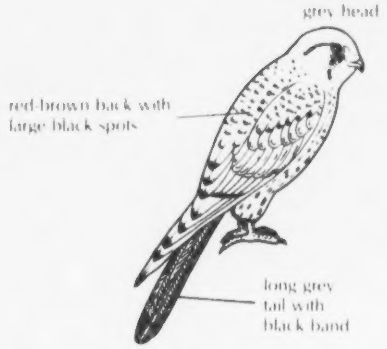
Size: 17 inches
Lives in: sandy, muddy and rocky shores
Eats: cockles, mussels and other shell fish


brilliant orange bill
black head, breast and upper parts contrast with gleaming white underside
thick, rather short pink legs

▶

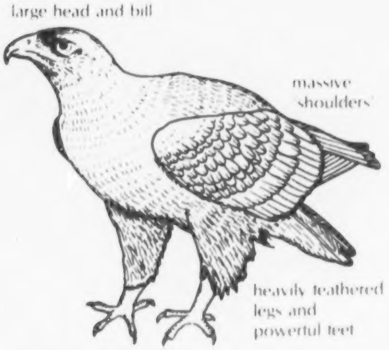
Kestrel

Size:	14 inches
Lives in:	hollow trees, cliffs, old nests, buildings
Eats:	beetles, mice, worms, small birds


grey head
red-brown back with large black spots
long grey tail with black band

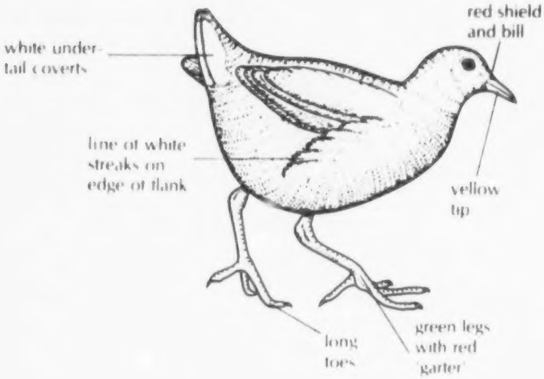
Golden eagle

Size:	35 inches
Lives in:	mountain ledges, forests, sea cliffs
Eats:	dead animals, rabbits, hares, small and medium sized birds


large head and bill
massive 'shoulders'
heavily feathered legs and powerful feet

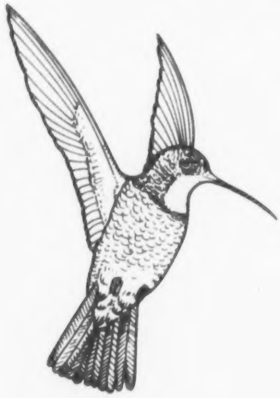
Moorhen

Size:	13 inches
Lives in:	ponds, lakes, marshes
Eats:	seeds, fruits, insects, water weed, tadpoles


white under-tail coverts
red shield and bill
line of white streaks on edge of flank
yellow tip
long toes
green legs with red 'garter'

Humming bird

Size:	2 inches
Lives in:	tropical rainforests in the Amazon
Eats:	nectar from flowers



Activity 23: Explaining states of matter

Formal models

Introduction

At first sight, this looks like a relatively straightforward 'states of matter' exercise. In fact, we are more interested in the pupils becoming aware of their own processes of observing, describing, and especially *explaining*. We certainly do not expect them to come up with a fully articulated particle theory of matter – they may not mention particles at all, even if they have 'done' particles already. The point is that they attempt to find a model to explain what they observe. Thus, the idea of an explanatory model should start to emerge.

Apparatus summary

Per pupil

- Safety glasses
- Worksheet

Per group

- Bunsen, tripod, triangle, crucible, tongs, etc.
- Samples of: ice, wax, sulphur, lead or solder

For demonstration

- Iodine, stearic acid

Procedure summary

1 This exercise is about observing, describing, and *explaining*.

2 Go over the '*rules* for heating things'. Demonstrate warming stearic acid gently until it melts, then heating until it starts to boil. Use the words solid, liquid, melt, boil, and condense.

3 Pupils heat ice, or wax, using the correct words when recording.

4 As each group finishes one substance, give them the next one. Warn them not to smell the fumes from sulphur. Demonstrate the iodine.

5 The 'explanation' part is the whole point of the exercise. Pupils look for explanations that satisfy them; you ask questions, pushing their models a bit.

6 After the activity, note any 'explanations' to use to start the next activity.

Procedure details

1 The first part of this exercise will be to **observe** carefully what happns, and **describe** it as well as possible. On the Worksheet are some words which pupils may use to describe what they see. Later, they will try to **explain** their observations.

2 Some of the substances to be heated can be dangerous if treated carelessly. Go over the normal rules for heating things including wearing safety glasses, never pointing the tube at anyone, heating gently at first, and shaking the contents.

Do the first one as a demonstration. Put stearic acid crystals into a boiling tube to a depth of about 3 cm, and make sure that all have seen what it looks like before you start to heat it. When it melts, ask pupils what has happened. In the discussion the words solid, liquid, and melt should be used. Now continue to heat, until the liquid starts to boil. Again pause, ask for a descrtiption of what has happened, bringing in the word boil. Carry on heating for a short time. They may have to come close to see liquid condensing in the cooler upper part of the tube, and running back down. How did the liquid get from the bottom to the upper part of the tube? The discussion can include the words vapour, the same thing as gas, and also condense. This may be a new word. (Stearic acid vapour does burn, but it has a relatively high boiling point and vapour is unlikely to escape from the tube unless it is heated very strongly for some time.)

3 Give out the first of the substances (ice or wax) that pupils are to heat, already in test tubes. Help them to get started, and to use the correct words when recording their observations.

4 As each group finishes one substance, give them the next one in a test tube (lead/solder in a crucible). If a group is behaving irresponsibly do not let them have sulphur. When you do give it out, warn them not to smell the fumes, and not to heat it so strongly that fumes come out of the tube. You will have to demonstrate heating iodine.

5 The 'explanation' part is really the whole point of the exercise, and yet one cannot prescribe how to manage it. If they have already met particles, pupils may suggest this as an explanatory model. We simply want them to struggle with the idea of looking for an explanation, whatever they come up with. Do *not* suggest particle theory if it does not arise anyway. Be 'non-directive' in discussing ideas, accepting virtually anything, but asking questions and pushing their models a bit.

6 After the activity, read all the 'explanations', and note common or interesting ones which you can use to start the next activity.

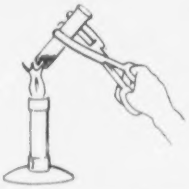
Your name: ....

Activity 23: Worksheet
Explaining states of matter

Formal models

1

Carefully *observe* what happens when your teacher heats the first substance.



2

In the table below *describe* what you saw happen.

Some of these words may help you:

melt, boil, freeze, gas, solid, liquid, condense, evaporate, solidify.

3

Now you will heat the other substances.

Remember:

- use a clean test tube each time;
- wear safety glasses;
- never point the test tube at anyone.

Name of substance	What I saw happen
Stearic acid	
Ice	
Wax	
Lead	
Sulphur	
Iodine	

4 *Now answer these questions*

1 You saw each substance in three different forms. These were

.... , ... , ...

2 Can you think of a way that all of the substances are made up, that would *explain* how they can melt and boil, consense and solidify? On the back of this sheet, write a story and/or draw pictures to explain how substances can change from solids to liquids, from liquids to gases and back again.

Activity 24: Explaining solutions

Formal models

Introduction

A direct parallel to the activity on explaining states of matter – this time the phenomenon is solution. The accepted 'scientist's explanation' is the same as for changes of state, but we still do not push particle theory, and pupils may well come up with completely different models.

Apparatus summary

Per pupil

- Worksheet

Per group

- Test tubes and corks, Bunsen, tripod and gauze, 250 cm^3 beaker and watch glass to fit over beaker
- Samples of sodium chloride, sulphur powder, copper sulphate

For demonstration

- A boiling tube, naphthalene, propanone (acetone)
- Optional: copper sulphate solution in a distillation apparatus

Procedure summary

1 Explanations given for the changes of state from the last activity are used to focus on the meaning of 'explanation', as distinct from redescription.

2 Point out the words on the Worksheet that they might use – they will not understand all of them yet.

3 Demonstrate: add water to a spatula full of naphthalene in a boiling tube and shake. If the liquid becomes clear, the substance dissolves. Naphthalene does not dissolve in water.

4 Pupils test solubility of each of the other solids and record observations. Ask which ones dissolved, which were insoluble.

5 Other solvents: things which are insoluble in water may dissolve in other solvents. Demonstrate the solubility of naphthalene in propanone, and allow some of the solution to evaporate in the sun (away from Bunsens).

6 Pupils evaporate salt solution over a water bath, and compare with the propanone solution that has been left to 'dry'.

7 Pupils should have a good chance to write and/or draw explanations. If time, demonstrate simple distillation of copper sulphate solution.

Procedure details

1 Spend time going over the explanations given for changes of state (Activity 23). Use examples to illustrate what constitutes an explanation, as opposed to a repeated description. You may be able to 'test' the models. For instance if someone said that heat makes the solid 'push apart' or 'open up', you could ask *what* pushes apart, *what* opens up? And why does heat make it do this? The purpose is to focus on the meaning 'explanation', and to give those (the majority?) who have thought of no explanations an idea of what you are looking for. It is not to come up with some final agreed idea.

2 Point out the list of words in the Worksheet introductory section that they might use – it doesn't matter if they do not understand all of them yet.

3 Demonstrate what to do, using naphthalene. Put a spatula full in a boiling tube, add water to less than half full, stopper the tube, and shake. If a substance dissolves the liquid will become completely clear. Naphthalene does not dissolve in water, and even after shaking for a minute or two, the white crystals can still be seen.

4 Give out the other solids, in test tubes, one at a time. Pupils test each for solubility and record what they observe. When they have finished ask which ones dissolved, which were soluble; get them to use both words. Which ones were insoluble, did not dissolve, and so on.

5 So far the only solvent they have tried is water. Discuss other solvents such as white spirit for oil paint, nail varnish remover for nail varnish, and dry cleaning fluid for oily stains. It seems that some things which are insoluble in water are soluble in other solvents. Demonstrate the solubility of naphthalene in propanone. Pour a little of the solution into a watch glass and stand it on a window sill away from the benches where they will soon be lighting Bunsens.

6 Taking one of the ones that dissolved in water, say salt, ask where is the salt now? Is there still the same amount of salt? Could they get the salt back? If necessary remind them of evaporation from the last lesson. Show the apparatus. The purpose of the water bath is to get gentle evaporation. While waiting for their solution to evaporate, they can answer questions in section 4 on the Worksheets.

The results of their own evaporation can be compared with the naphthalene/propanone solution that has been left to 'dry', and then they answer questions in section 5.

7 What you do next depends on timing. The most important thing is that pupils should have a good chance to write and/or draw explanations (in the jargon, construct their own theoretical models) for the phenomenon of dissolving, and evaporating off a solvent (Worksheet section 6). If you only have five or ten minutes left, that is all there will be time for. If you have more time, you could discuss their answers to the question 'How do you get the solvent back from a solution?' Show the distillation apparatus, explain how the condenser works, and demonstrate it in action, up to the point where you start to get a few drops of water condensing in the receiving flask. This provides more observation which has to be explained by the model.

Your name: ....

Activity 24: Worksheet Explaining solutions

Formal models

1

Carefully *observe* what happens when your teacher shakes the first substance with water.

2

In the table below *describe* what you saw happen. Some of these words may help:

dissolve, soluble, insoluble, solution, solute, liquid, solid, solvent.

3

Test the solubility of the other substances.

- use a clean test tube each time.
- take only a very little of each solid.

Name of substance	*What I saw happen*
Naphthalene	
Salt	
Sulphur	
Copper sulphate	

4

Now answer these questions:

Which of the substances that you tried were soluble in water?

.... , ... , ...

Which ones were insoluble?

.... , ... , ...

a Does naphthalene dissolve in water? ....

b Does it dissolve in any other solvent? ....

c If so, what solvent dissolves naphthalene? ....

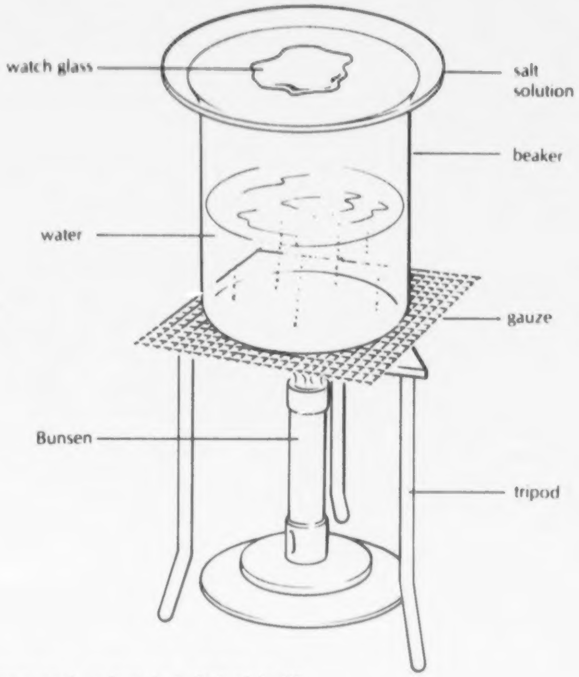
After sugar has dissolved in tea, where is the sugar?

....

Your name: ....

5

Use apparatus like this to evaporate some of the salt solution:


watch glass
salt solution
beaker
water
gauze
Bunsen
tripod

After the salt solution has evaporated, what is left behind?

....

Where has the solvent (the water) gone?

....

Can you think of a way of getting pure solvent back from a solution?

....

....

....

6

Can you think of a way that substances are made up, that would *explain* how they can dissolve in liquids, and how they can be recovered again?

Write a story and/or draw pictures to explain *dissolving*.

Activity 25: Explaining chemical reactions

Formal models

Introduction

This is the third and last of the 'explanation' interventions, in which pupils must construct, or at least use, a formal model as an explanation. This time the phenomenon is chemical reaction. Now we can propose particle theory as an explanation, and the pupils' task is to make what she or he has observed fit with such a model.

Apparatus summary

Per pupil

- Worksheet

Per group

- A candle, Bunsen, boiling tube and test tubes
- Samples of: sulphur powder, copper turnings, granulated zinc, dilute sulphuric acid

For demonstration

- Asbestos mat, sulphur powder, iron filings, spatula

Procedure summary

1 Read out some of the 'explanations' from the last activity. Make something of any which use particle theory.

2 Pupils light candles. Emphasise the need for careful observation. Some points are: it is the wax that burns, the candle gets smaller, air is needed, it would not be easy to get the candle back from the products.

3 Pupils observe sulphur powder and copper turnings separately, then mix and heat them. The copper goes black as copper sulphide is formed. Again a new substance has been formed from which it would be difficult to get back the copper and sulphur.

4 Demonstration: show iron filings, then mix in sulphur powder, and spread the mixture in a line across an asbestos mat on a tripod. Heat with a Bunsen from above – once started it continues without further heating. A point is that energy is given out during this (and many other) chemical reactions.

5 They add granulated zinc to dilute sulphuric acid in a boiling tube.

6 The most important thing is that pupils should have a good chance to write and/or draw explanations. This time, suggest that some sort of account in terms of particles might satisfactorily explain the observations in this and the last two activities.

Procedure details

1 You could again start by reading out some of the 'explanations' which people gave for the dissolving and evaporating exercise in the last activity. This time, make a bit more of any explanations which use particle theory, possibly getting anyone who has used this to say more about how it explains what was observed.

2 This time they are going to look at some chemical reactions – there is no need to 'define' or otherwise enlarge upon the meaning of chemical reaction at this point.

Give out the candles, emphasise that they must observe very carefully what happens, and let them light them and get on with the first activity. The points to develop are that:

- it is the wax that burns,
- the candle gets smaller as wax is 'used up',
- if there was no air, the candle would go out (if necessary they can try this),
- what is produced (the 'products') are probably gases which escape; it would not be easy to get the candle back from the products.

Question 10 actually asks for an explanation in terms of particles. This may need some assistance.

3 Give out to each group sulphur powder, just filling the rounded bottom of a test tube, and a spatula full of copper turnings in another test tube or on a filter paper. They observe the separate substances and describe them, then mix and heat them. The copper goes black as copper sulphide is formed. Again the point is that a new substance has been formed and that it would be difficult to get back the copper and sulphur from the copper sulphide.

4 The next reaction is one that you should demonstrate. It is worth doing as it adds another important feature of chemical reactions.

Show the class some iron filings. Mix together well about equal volumes of iron filings and sulphur powder, a good teaspoonful of each. Spread the mixture in a line across an asbestos mat on a tripod. Hold a Bunsen above the mat, pointing down on to one end of the line of mixture, until the reaction starts. Once started it continues without further heating. A glow is seen to pass down the line as the reaction proceeds.

A new substance, iron sulphide, is formed. It would be difficult to get back iron and sulphur from iron sulphide. In addition an important point is that energy (heat) is given out during this (and many other) chemical reactions.

5 The last experiment that they do is to add a couple of pieces of granulated zinc to dilute sulphuric acid. Often not much happens at first, especially if the zinc is pure. Then it needs to be warmed to start the reaction. This should be done in a boiling tube. If anyone is really keen to see what happens if the resulting solution is evaporated and there is time, let them try it using a clock glass over a water bath. The white solid left (zinc sulphate) is obviously quite different from either the zinc metal or the sulphuric acid that they started with. This a very different situation to the simple solution of salt in water.

If things are reasonably calm, some could also test the gas that comes off with a lighted splint – the 'pop' shows that it is an explosive gas, obviously not just steam or a gas of the atmosphere.

6 In conclusion, the most important thing is that pupils should have a good chance to write and/or draw explanations. This time, you can try to suggest that some sort of account in terms of particles might be a satisfactory way to explain what they have observed. What is more, the idea that matter consists of particles can also be used to explain the quite different phenomena they have seen in the last two interventions – change of phase, and solution. There is absolutely no point in forcing this explanation, or too much spoon-feeding. The purpose is to offer apparently straightforward phenomena which are in need of some all-embracing explanation, and then to provide the opportunity to use a given formal model as an explanation.

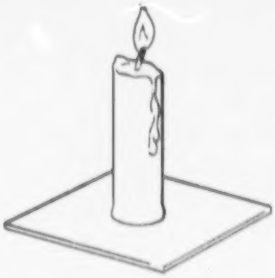
Your name: ....

Activity 25: Worksheet
Explaining chemical reactions

Formal models

1 Candle

Place a candle on an asbestos mat. Light the candle and watch carefully what happens.



1 When the candle burns, what happens to the wax around the wick? ....

2 Does the candle get smaller as it burns? ....

3 What is burning? ....

4 Where do you think the wax is going?

....

5 Could you collect it again? ....

6 Is this the same process as water evaporating? ....

7 If not, how is it different? ....

....

8 Would the candle burn if there was no air around it? ....

9 Is air (or part of the air) used up when a candle burns? ....

10 Try to *explain* what happens when a candle burns, using the idea that there are oxygen molecules in the air, and wax molecules in the candle.

....

....

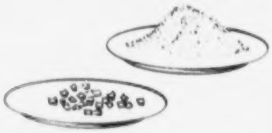
....

....

▶

Your name: ....

2 *Copper and sulphur*



Look carefully at some sulphur powder and some copper. Describe what they look like (first two columns of the table).

Before heating		After heating
Copper	Sulphur	– the product

Mix the copper and sulphur together in a test tube.
Heat the mixture, gently at first and then more strongly.
In the third column of the table, describe what the product left in the test tube looks like.

The black product is called *copper sulphide*.

1 Do you think you could get copper and sulphur back from copper sulphide? ....

2 What do you think has happened to the particles (atoms) of copper and the particles (atoms) of sulphur?

....

3 Is this the same sort of thing that happens when sulphur alone is melted in a test tube and allowed to cool again? Explain your answer.

....

....

3 *Iron and sulphur* (demonstration)

1 After the iron and sulphur have started to react, the burner is taken away. What do you see?

....

2 Does the iron sulphide that is formed look like either the iron filings or like the sulphur powder?

....

3 Try to explain what has happened in terms of the atoms of iron and the atoms of sulphur.

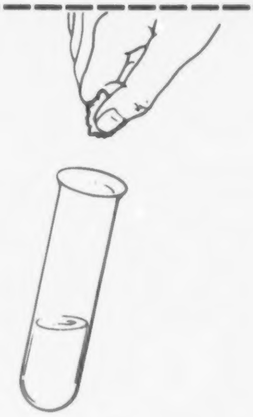
....

....

▶

Your name: ....

4 *Zinc and sulphuric acid*



Your teacher will give you some sulphuric acid. Be careful not to spill it. If you get any on your hands or clothes, wash it off immediately with water.

Put some pieces of zinc into the acid.
Watch carefully what happens.
If nothing happens, light a bunsen and warm the mixture *gently*, while shaking it.

1 What do you observe while the zinc and acid react?

....

....

2 Where does the zinc go? ....

3 Is this the same sort of thing that happens when salt dissolves in water? Please explain your answer.

....

....

4 Do you think you could get the zinc back? If so how?

....

....

If there is time, ask your teacher if you can try your idea.

5 What do you think is happening to the atoms of zinc and the molecules of sulphuric acid?

....

....

....

Activity 26: Pressure

Compound variables

Introduction

This is the first activity about compound variables. A **compound variable** is one made up of two other variables – for instance pressure is defined as force/area, density as mass/volume, and momentum as mass × velocity. To use a compound variable fluently one has to be able to handle the ratio or product as one variable, at the same time as seeing it as made up of two variables each of which can change independently. Eventually we want to abstract the idea of compound variables from any particular examples such as pressure or density.

Apparatus summary

Per group

- Dowel or square section rods of various diameters (some can be shared between groups), each with a hardboard square attached
- Trays of damp sand
- Slotted weights

For demonstration

- Bottle of orange squash, water, measuring cylinder, drinking glasses
  (There is no Worksheet, but pupils will need paper or exercise books.)

Per pupil

- Workcard

Procedure summary

1 Discussion of high heels: why do they sink into ground more than flat shoes? What are the variables? *Weight* and *area* on the ground.

2 Show the rods and sand trays. Pupils have to design an experiment to investigate the effects of weight and area on the depth that the rods sink.

3 Groups carry out their experiments and record results and conclusions. Aim for at least 'The thinner the rod the more it sinks in; the heavier the weight the more it sinks in'.

4 To predict how deep the rod will sink, both variables have to be considered. Two variables combined are a **compound variable**.

5 You could give some imaginary results from which they work out that the weight:area ratio is constant. The scientific word for weight/area is **pressure**.

6 If time, introduce concentration. Make orange squash using different volumes diluted differently. Volume of squash/volume of drink is the compound variable – **concentration**.

7 Do Workcard questions

Procedure details

1 Introduce the problem with a discussion of high heels – why does a light girl (or a light boy for that matter) wearing high heels sink into the ground/parquet floor more than a heavy person with flat shoes? People wearing snow shoes or skis don't seem to sink even into soft snow.

What are the variables? It must be something to do both with *weight* and with the *area* on the ground.

2 Show the dowel rods with the tops, which will support weights, and the sand trays. Set the pupils, individually or in groups, the task of designing an experiment to investigate the effects of (a) weight and (b) area on the depth that the rods sink into sand. Leave them to get on with this task, with drawings and/or writing on paper or in exercise books. Some will need guidance towards designing 'fair' tests – a number of different diameter rods with the same weight on each, and one rod with a number of different weights.

3 As soon as each group has a more or less satisfactory design, they can carry out their experiment and record results and conclusions. You should aim for at least 'The thinner the rod the more it sinks in; the heavier the weight the more it sinks in'. For some you could ask additional compensation questions: 'If I use a thicker rod, what must I do to the weight to make it sink in the same distance?'

The most able may be able to quantify it – 'If you double the area, and halve the weight, it sinks in the same amount'. Finding the cross-sectional area of square section rod is easier than dowel if the former is available.

You might make a display of the designs and results.

4 Call the class together to discuss conclusions. What are the variables involved? Weight and area. Can one predict how deep the rod will sink, if you only know the *weight* on it? . . . if you only know its *thickness* (cross-sectional area)? No, you have to think of both variables together before a prediction can be made. When you have to combine two variables like this, you have a **compound variable**.

5 Where you go from here depends on the ability of your class. You may be able to introduce the word *pressure*. You could, for instance, give them some of 'your' results, such as:

'I found that all of the following rods sunk exactly the same depth into sand.'

Thickness(cm^2)	Weight (g)
0.75	75
1.00	100
1.50	150
2.00	200
3.00	300

(To be correct, and if pupils are familiar with it, weights should be expressed in newton.)

Pupils work out that the weight:area ratio is the same in each case. It is the weight/area combination that determines how deep the rod goes into the sand. Then you can give them the scientific word for weight/area – **pressure**. Pressure is a compound variable.

What happens to the pressure if you increase the weight? What happens to the pressure if you reduce the area, keeping the same weight?

6 But you may not be able to quantify it like this. Instead (or as well if time), introduce another compound variable – concentration. Make yourself some orange squash – pour 25 cm^3 of concentrated squash into a measuring cylinder, make up to 250 cm^3, and pour into a glass.

Repeat using 10 cm^3 of squash made up to 100 cm^3. Are these drinks the same strength? Try again with 10 cm^3 of squash made up to 250 cm^3. Obviously this is weaker. How can the strength of orange squash be described? The variables are volume of squash taken, and volume of drink made. To describe the strength of the drinks, you need both together: volume of squash/volume of drink is the compound variable – called **concentration**.

7 There are problems on the Workcard.

Workcard Answers

1 Tina
2 Bruce
3 Weight, area
4 Pressure
5 Doris
6 Imran
7 Leslie
8 Samantha
9 Doris will sink in deepest, Tracey the least.
12 The first is weaker, the other two the same.
13 Volume of concentrate, volume of water (or volume of final drink).
14 Concentration.
15 How concentrated it is.

Activity 26: Workcard Pressure

Compound variables

Sinking

Tiny Tina and Big Bruce go for a country walk together. Tina weighs 50 kg. She wears high heeled shoes. The area of her shoes on the ground is 25 cm^2.

Bruce weighs 75 kg. He takes size 12 boots which have an area on the ground of 150 cm^2.

1 Who will sink deeper into the mud? How do you work out your answer?

2 Tina changes into trainers which have an area on the ground of 125 cm^2. Now who will sink deeper into the mud? How do you work it out?

3 What are the variables you had to think about to solve this problem?

4 What is the compound variable you use to tell how deep an object will sink into soft ground?

On a school trip to the seaside, a group goes for a walk on the beach. Some walk in pairs. For each of the following pairs, say which one will sink deeper into the sand:

		Weight	Shoe area
5	Doris	60 kg	30 cm^2
	Charlie	70 kg	140 cm^2
6	Imran	65 kg	130 cm^2
	Bill	55 kg	130 cm^2
7	Leslie	50 kg	150 cm^2
	Tracey	60 kg	200 cm^2
8	Brian	75 kg	100 cm^2
	Samantha	60 kg	60 cm^2

9 Which one of the eight people will sink deepest into the sand? Who will sink in the least?

10 Why does a pin have a point?

11 Why does an elephant have flat feet?

▶

Hoorah for lemon barley water

Terribly Trendy Tricia *adores* tennis. But she does get thirsty, and likes a large glass of lemon barley water by the tennis court.

Tricia could have:

$10\ cm^3$ barley water made up to $100\ cm^3$ with water, or
$20\ cm^3$ barley water made up to $100\ cm^3$ with water, or
$10\ cm^3$ barley water made up to $50\ cm^3$ with water.

12 What is the difference between the drinks?

13 What are the variables?

14 What is the compound variable?

15 A bottle of concentrated orange squash costs 64¢ It contains $350\ cm^3$. What else do you have to know before you can work out the cost of one glass of diluted orange squash drink?

Activity 27: Floating and sinking

Introduction

The compound variable **density** is tackled through experiences of bouyancy. In trying to predict whether or not jars will float or sink, students find that neither volume nor mass *alone* provide sufficient information. Both must be considered together.

Apparatus summary

For demonstration

- Simple balance, aquarium with enough water to sink largest jar
- Two sets of jars:
  (a) five of the same volume, varying masses, labelled A–E
  (b) six of the same mass, varying volumes, labelled 1–6
- Two extra jars, X and Y

Per pupil

- Worksheet
- Workcard B

Per pair

- Set of 'playing cards' –Workcard A

Procedure summary

1 What makes things float or sink? What are some of the variables that might be investigated?

2 How might one investigate whether *mass* affects floating/sinking?

3 Show the class the collection of jars (excluding X and Y). Weigh each and try it in the water. Pupils write F or S on the picture of each jar on their worksheet. The heavier the jar, the more likely it is to sink.

4 Do the same for the jars of different size, same mass. The smaller the jar, the more likely it is to sink.

5 This is the critical part of the activity. Jar X is the same *size* as jar 4 (which floats) and the same *mass* as jar C (which floats). Pupils predict whether it will float or sink. Then demonstrate: it sinks. Do the same for jar Y.

6 Introduce the card game. The pattern is a diagonal dividing the floaters in the top left from the sinkers in the bottom right.

7 *Both* volume *and* mass have to be considered before an accurate prediction can be made about floating/sinking. Neither alone is enough. The compound variable is called **density**; it is a *ratio* of mass:volume.

8 Workcard B has problems to consolidate ideas.

Procedure details

1 The lesson is an investigation into what makes things float or sink. Pupils know that large heavy things like ships float, while small light things like pins can sink. What are some of the variables that might be investigated? Answers could include mass, size (volume), amount of air, surface area, and others.

2 Discuss briefly how an experiment might be planned to investigate whether *mass* affects floating/sinking. Do not give a prescribed 'control of variables strategy', but leave the discussion open-ended. For some pupils the idea of objects all of the same volume but of different mass should occur.

3 Show the class the collection of jars (excluding X and Y). Starting with the series which are all the same volume, get a pupil to help weigh each in turn and then try it in the water. Pupils write F or S on the picture of each jar on their Worksheet to show whether it floats or sinks.

What conclusion can be drawn? Nothing remarkable so far – the heavier the jar, the more likely it is to sink.

4 Starting again with jar A/6, do the same for the jars of different size. Pupils should note that they are all the same mass. The conclusion here is a little odder, but still straightforward – the smaller the jar, the more likely it is to sink.

5 This is the critical part of the activity. Produce jar X. Show that it is the same *size* as jar 4 (which floats) and the same *mass* as jar C (which floats). On the Worksheet show where on the chart jar X should be shown. They can draw it in if you like, or just put an X in that box. The important thing is for them to make a prediction whether it will float or sink (questions 1 and 2 on the Worksheet). When all have answered ("don't know" is a respectable answer), demonstrate: it sinks.

This often comes as something of a surprise, a good moment of 'cognitive conflict'.

Do the same for jar Y. This time they are likely to be less ready to make predictions.

6 Now introduce the card game. The rules are on the Worksheet, but you will probably have to go through them. They should play until all of the cards have been put on charts. The pattern is a diagonal dividing the floaters in the top left from the sinkers in the bottom right.

7 The essential message is that *both* volume *and* mass have to be considered before an accurate prediction can be made about floating/sinking. Neither alone is enough. Questions such as 'A tanker weighs 300 000 tonnes full – will it float?' cannot be answered unless one knows the volume of the tanker.

The following ideas are part of the schema – go as far with them as time/ability/interest allow:

- To predict floating, the combination of mass and volume you need is a **compound variable**.
- The compound variable is called **density**.
  (Lots of practice with word, contexts, etc.)
- The compound variable, density, is a **ratio** of mass:volume. (practice with some simple calculations).
  (If you get that far, and they really understand it, you might as well put them all in for early Oxbridge entrance and go home.)

8 There are problems on Workcard B to consolidate ideas of floating, sinking, and compound variables. It includes a new compound variable, *momentum*. Again, it is the idea of two variables together, mass and speed, which is important. In this case the compound variable is the product, not the ratio, of two simple variables.

Workcard B Answers

1 Sinks
2 Floats
3 Sinks
4 Floats
5 Floats
6 Mass and volume
7 Density
8 Must be greater than $3000\ cm^3$
9a Greater than 5 g;
9b Less than 5 g.
2 1–4 Momentum of
jeep = 2000 g.k.p.h.
pea = 1000 g.k.p.h.
lead = 4000 g.k.p.h.

Your name: ....

Activity 27: Worksheet
Floating and sinking

Compound variables

On the chart (p.2 of Worksheet), write in the mass of each jar. Write F or S on each jar to show whether it floats or sinks.

1 Mystery jar

1 Do you think jar X will float or sink? float/sink/don't know

2a If you answered 'float' or 'sink', why do you think so?

....

....

b If you answered 'don't know', what else do you need to know?

....

3 Do you think jar Y will float or sink? ....

Explain how you made your prediction.

....

4 What are the variables you have to consider before you can say whether something will float or sink?

....

2 Pattern of floating

Play the 'floating and sinking' card game:

Divide the pack in two, one half to each player. (Workcard A)

Player A puts one card on the table, *jar side up*.

Player B looks at the weight and size, and says whether it will float or sink.

Turn the card over – it will have an F if it floats or an S if it sinks. If player B got it right, she/he puts the card in the right place on his/her worksheet chart. If player B was wrong, player A puts the jar on her/his own chart.

Put the cards on the chart with the F or the S facing up.

Then it's B's turn to show a card, and A's to say float or sink.

What *pattern* of floaters and sinkers do you see on the chart?

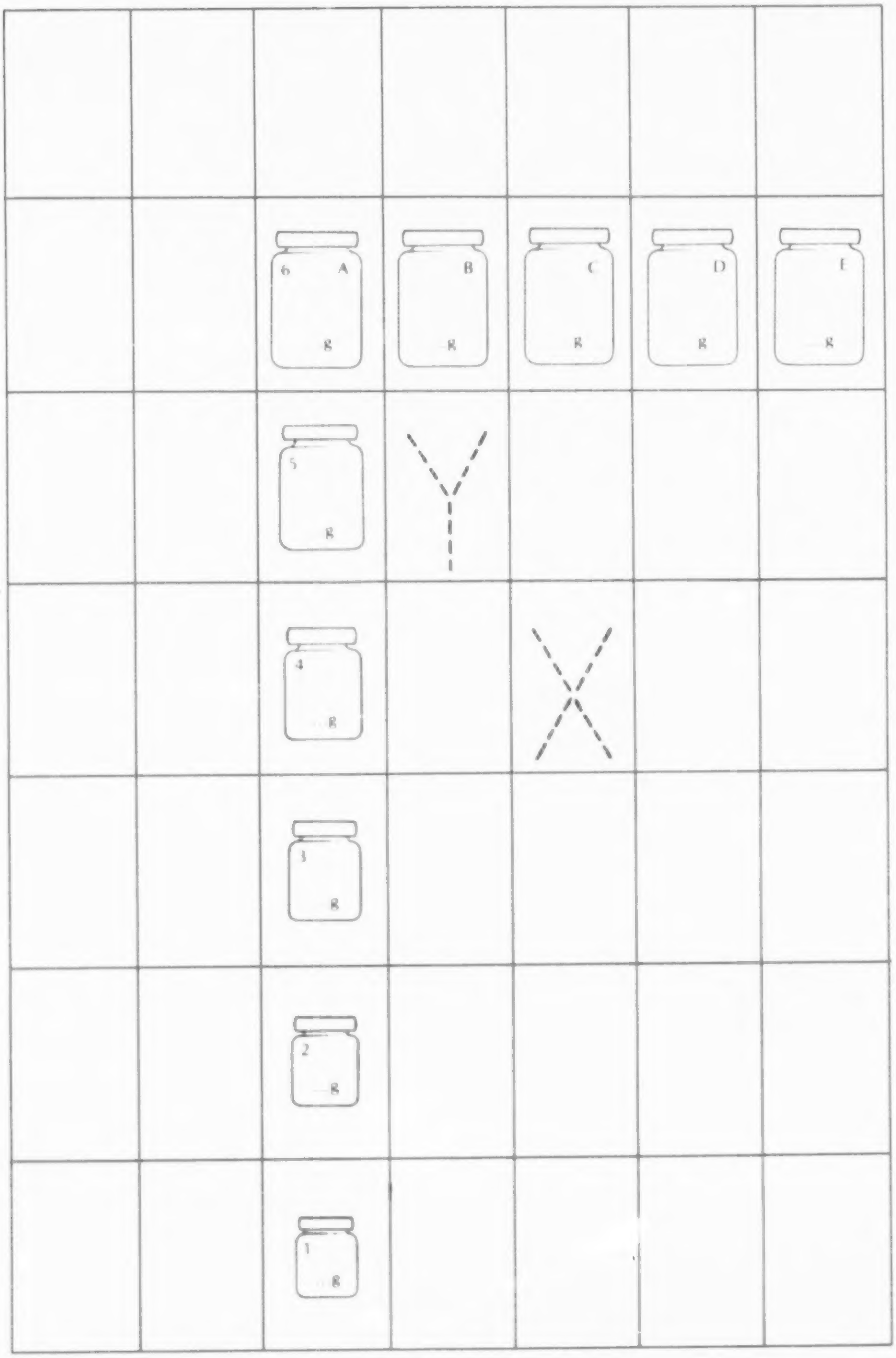
....

....

▶

Your name: ....

THINKING SCIENCE
ACTIVITY 27
WORKSHEET p.2


6
A
g
B
g
C
g
D
g
E
g
5
g
4
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3
g
2
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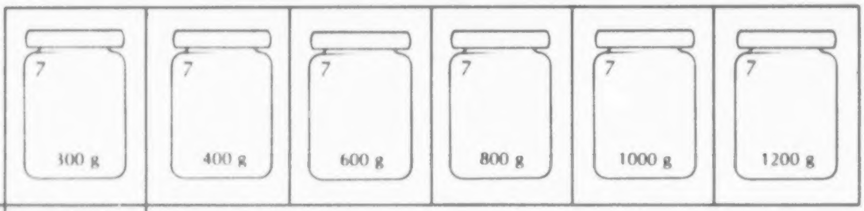
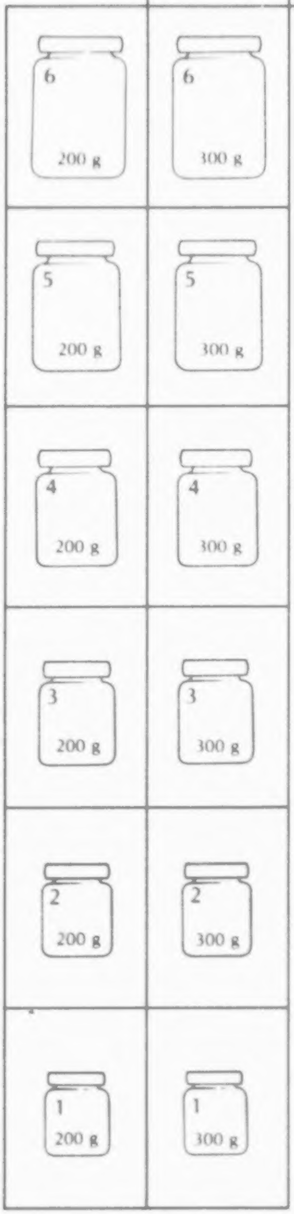
1
g

Activity 27: Workcard A
Floating and sinking

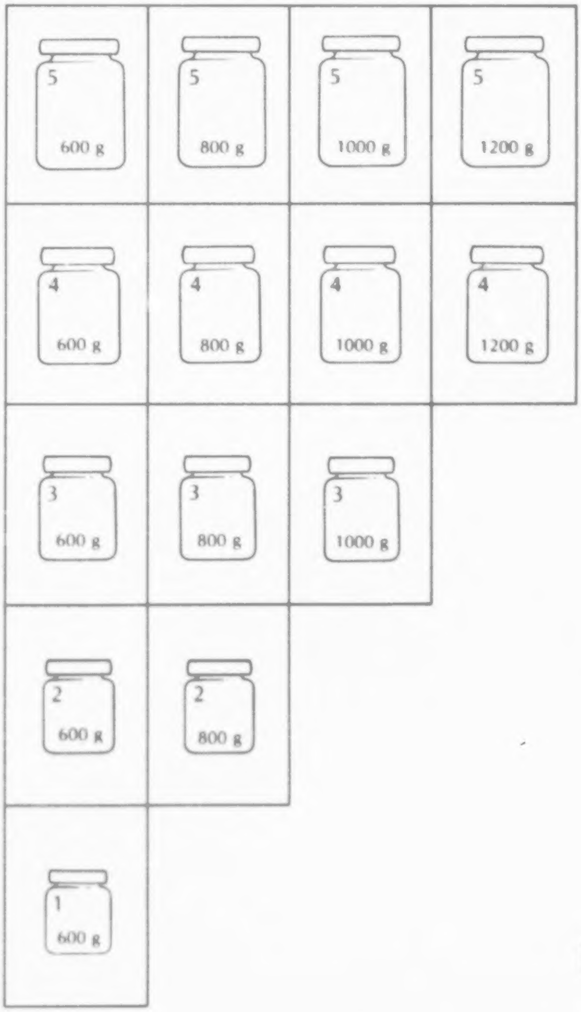
Compound variables


7 300 g
7 400 g
7 600 g
7 800 g
7 1000 g
7 1200 g


6 200 g
6 300 g
5 200 g
5 300 g
4 200 g
4 300 g
3 200 g
3 300 g
2 200 g
2 300 g
1 200 g
1 300 g

Note

The card set should be cut into squares to make a set of 32 cards.


5 600 g
5 800 g
5 1000 g
5 1200 g
4 600 g
4 800 g
4 1000 g
4 1200 g
3 600 g
3 800 g
3 1000 g
2 600 g
2 800 g
1 600 g

►

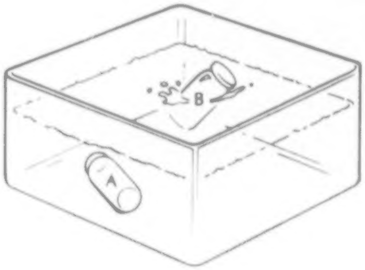
S	F	F	F	F	F	
					F	F
S	S	F	F		F	F
S	S	S	F		F	F
	S	S	S		F	F
		S	S		S	F
			S		S	S

Activity 27: Workcard B Floating and sinking

Compound variables

Problems

1 Floating and sinking

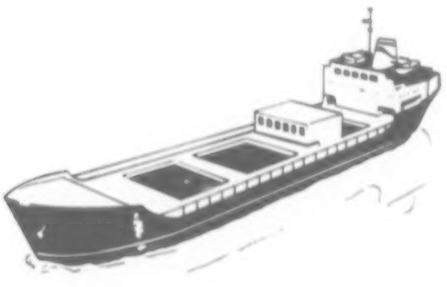


Jar A weighs 500 g and has a volume of 400 cm^3. It sinks in water.

Jar B weighs 600 g and its volume is 700 cm^3. It floats on water.

For each of the following jars, say whether it will float or sink in water, and why you think so:

1 Mass 500 g, volume 300 cm^3.
2 Mass 500 g, volume 750 cm^3.
3 Mass 250 g, volume 200 cm^3.
4 Mass 1500 g, volume 1800 cm^3.
5 Mass 900 g, volume 1200 cm^3.
6 What are the variables you have to think about to work out these problems?
7 What is the compound variable you use to tell you whether something will float or sink?
8 A model tanker ship weighs 3000 g. If it is to float, what can you say about its total volume?



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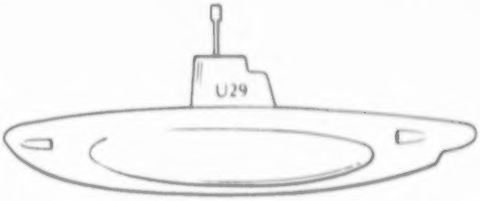
9 I got a plastic submarine out of my cereal packet this morning. Sometimes it floats and sometimes it sinks. Its total volume is 5 cm^3.

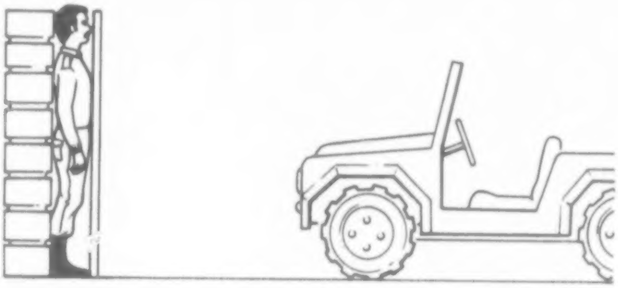


a What must its mass be to make it sink

b What must its mass be if it is to float?

2 *Stop that jeep!*

Guerilla Gus has captured his enemy, Perfect Peter. Peter is held between a brick wall and a board.



Gus says:

'Now you may choose: would you prefer me to run my jeep (mass 1000 kg) at you at a speed of 2 k.p.h., or shoot a pea (mass 5 g) at you at 200 k.p.h.

1 How does Peter choose?

2 What are the variables?

3 What is the compound variable?

4 What if the pea is replaced by a lead shot, mass 20 g, also shot at 200 k.p.h.?

(Brainy Brenda thinks the lead shot is worse than the jeep, and the jeep is worse than the pea. How does she work it out?)

Activity 28: Up hill and down dale

Equilibrium

Introduction

The schema of equilibrium involves *four* variables. For instance, in the balance beam there is the weight on one side and its distance from the fulcrum, and the weight on the other side, and *its* distance from the fulcrum. Each of these can be altered independently, and if the system was in equilibrium and one is changed, then equilibrium can be restored by altering any one of the other three. In this activity, the variables are the weights of the cars and the slopes of the hill on each side.

Apparatus summary

Per group

- Two cars rest on slopes which form two sides of a hill. The cars are joined by a thread running over a pulley at summit. The slopes can be altered, and weights can be added to the cars.

Per pupil

- Worksheet

Procedure summary

1 Discussion of 'equilibrium' could include tightrope walkers, riding a bicycle, and the beam balance.

2 Demonstrate with the apparatus that the equilibrium can be upset by altering either of the slopes, or the weight of either car.

3 Picture at the top of the Worksheet: could the car pull the truck up a hill, even with its engine off?

4 It is often difficult for pupils to see the weight of one car and the weight of the other car as two independent variables. All should agree on the four variables before going on. (item 1)

5 They work through Worksheet items 2 and 3. You might call all together for item 4.

6 Most pupils will be able to start on the quantitative items and many will discuss usefully how to measure steepness. The most useful way is as a ratio, such as '1 in 10'.

Procedure details

1 What do pupils understand by the word 'equilibrium'? Discussion could include tightrope walkers, walking along a beam, riding a bicycle, and the beam balance. In all there is the idea of balance, of one side balancing the other.

2 Show one set of the apparatus. Demonstrate briefly that the cars are in equilibrium, but that the equilibrium can be upset by altering either of the slopes, or the weight of either car (use a glue stick to stick on a 10g weight).

3 Offer the picture at the top of the Worksheet as a problem: could the car pull the truck up a hill, even with its engine off? This is what they are going to investigate. Groups set up their own apparatus. Some will want help with this.

4 You could do question 1 as a class discussion, as it is often difficult for them to see the weight of one car and the weight of the other car as two independent variables. 'Length of string' is sometimes given. If so, either demonstrate or get them to try changing the length of string and seeing if this has any effect on equilibrium. It is important that all agree on four variables before going on to the next part.

5 They work through items 2 and 3. Again, you might call all together for item 4, the conclusion to the qualitative part of the experiment.

6 To see the quantitative items right through to conclusion would be very high level, but most pupils will be able to make a start (you find the weight of the cars with a balance . . .) and many will engage usefully in a discussion about how to measure steepness. 'Angle, with a protractor' is a perfectly good answer, although if they actually do this the weight × steepness calculation will not yield an obvious relationship.

For your background information only: the relationship is that, for equilibrium,

$$\text{weight} \times \sin(\text{angle}) \text{ on left} = \text{weight} \times \sin(\text{angle}) \text{ on right}$$

So tabulating the angles and weights that balance will not lead directly to a quantitative explanation. However, if steepness is measured as the ratio '1 in x', where x is the distance along the slope for every 1 cm vertical rise, then this is the same as the sin of the angle so the relatonship is, for equilibrium,

$$\text{weight} \times \text{ratio steepness on L} = \text{weight} \times \text{ratio steepness on R}$$

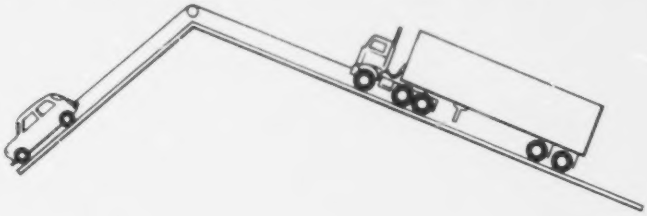
$$\text{e.g.} \quad 36\text{ g} \times 1/12 = 30\text{ g} \times 1/10$$

Your name: ....

Activity 28: Worksheet Up hill and down dale

Equilibrium

A little car can pull a big truck up a hill . . .



. . . if the hills have the right steepness.

1 What variables?

Try different ways to make two cars or trucks balance each other.

There are *four* things you can change that effect the balance.
What are the four variables?

.... (variable 1) .... (variable 3)

.... (variable 2) .... (variable 4)

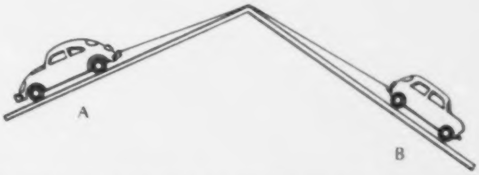
If the cars are balanced, the system is in **Equilibrium**

2 Changing a variable

Starting with the system in equilibrium, change one of the variables.

Show on this diagram:

a which variable you changed,
b in which direction, and
c what happened.

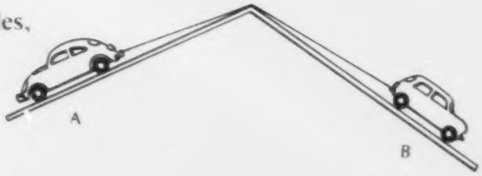


For instance, draw a weight on one of the cars, or draw the new slope of one of the hlls, and put an arrow to show how the cars moved.

3 Equilibrium again

Now, try changing *one* the other variables, until the system is in equilibrium once again.

Show which variable you changed, and in which direction.



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Your name: ....

4 *Summarising*

Explore the effect of changing each of the variables in turn. Summarise your conclusions like this:

'If the slope A is made steeper, then car A rolls down. The system can be brought back to equilibrium by

either: ....

or : ....

or : ....

Quantifying equilibrium

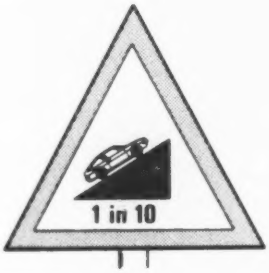
5 How could you measure the *weight* of the cars?

....

6 How could you measure the *steepness* of the hills?

....

....



7 Arrange the system in equilibrium in a number of different ways.

For each way, record the value of each of the four variables in the table below.

Arrange your results in an orderly fashion.

Variable 1	Variable 2	Variable 3	Variable 4
Left hand side A		**Right hand side B**	
Weight	Steepness	Weight	Steepness

Can you find a general rule describing the relationship between the weights of the cars (W_1, W_2) and the steepness (S_1, S_2) of the two hills?

....

....

Activity 29: Equilibrium in the balance

Equilibrium

Introduction

The four variable idea of equilibrium was introduced in Activity 28. This one is not such fun but is mathematically simpler. The four variables are investigated systematically, with the aim of developing a general rule to describe balancing situations. Superficially this looks like the first compensation activity (Activity 10) but there the emphasis was on one side of the beam at a time, so only two variables were involved at once. Here pupils look at both sides, encompassing all four variables. In addition pupils are encouraged to devise their own methods of recording data, rather than giving them ready-made tables.

Apparatus summary

Per group

- Balance beams with hole in centre and eight holes either side
- Two hangers and six 100 g slotted weights

Per pupil

- Worksheet and plain paper
- Workcard

Procedure summary

1 Recall the last activity; the four input variables were the weights of the two cars and the steepness of the two hills. This activity is simpler and they will be able to investigate the relationships more clearly.

2 The four input variables here are the weights on either side and distances from the centre on either side. Establish that all have the four variables before going on to the next section.

3 In the second section, pupils look for the four ways of balancing a 200 g and 400 g mass. They set up their own recording system.

4 They explore another combination of weights and find ways to balance them.

5 The idea of moment is introduced, leading able pupils to construct the law of moments for themselves.

6 There are Workcard problems.

Procedure details

1 Remind the class of the last activity involving cars on two hills. The four input variables were the weights of the two cars and the steepness of the two hills.

This activity is similar, but simpler, so they will be able to investigate the relationships more clearly. Understanding relationships allows predictions to be made, and prediction allows control – clear relevance to design and technology.

2 The first section of the Worksheet is to concentrate the minds on the four input variables – weights on either side and distances from the centre on either side. Each can be altered independently of the other. Establish that all have the four variables before going on to the next section.

3 In the second section, pupils look for the four ways of balancing a 200 and 400:

200 on 2 vs. 400 on 1
200 on 4 vs. 400 on 2
200 on 6 vs. 400 on 3
200 on 8 vs. 400 on 4

They are encouraged to set up their own recording system. Some will need help with this. They can use plain paper or an exercise book. Typically this will consist of a four column table, with a column for each variable, but individuals may develop their own systems, provided that they are orderly and likely to help them to see relationships.

4 Once the system is established, they explore another combination of weights, and record the ways they find to balance them (there are only two: 200 on 3 vs. 300 on 2, and 200 on 6 vs. 300 on 4.)

5 The last sections introduce the idea of moment, and reflect earlier work done on compound variables. For able pupils it will lead to them constructing the law of moments for themselves, with understanding.

6 There are Workcard problems.

Workcard Answers

1 Moment on A = 4, on B = 2. A goes down
2 Moment on A = 12, on B = 2. A goes down
3 Moment on A = 4, on B = 4. stays in equilibrium
4 Moment on A = 4, on B = 3. B goes down
5 A will go down, it is larger and steeper
6 B will go down. No force down the A side.
7 No 8 No 9 Yes 10 No

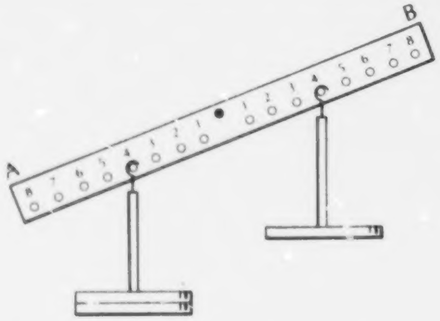
Your name: ....

Activity 29: Worksheet Equilibrium in the balance

Equilibrium

There are many ways to make a beam balance.

1 Ways of balancing



Start with:

a 200 g weight in hole 4 on side A, and
a 100 g weight in hole 4 on side B.

You can make this balance in *four* different ways, starting each time from this arrangement. (Keep the 200 g on side A, the 100 g on side B.)

What are the four ways?

1 ....

2 ....

3 ....

4 ....

What are the four variables you can alter to make the beam balance?

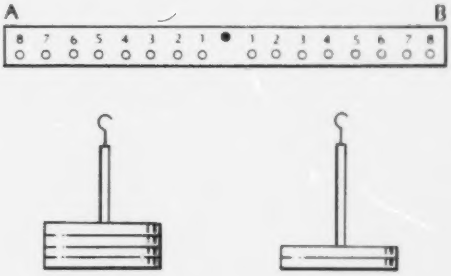
1 ....

2 ....

3 ....

4 ....

2 More ways . . .



Now take a 400 g weight and a 200 g weight.

Find one way to make them balance with the 400 on side A and the 200 on side B. Show on the drawing how you made them balance.

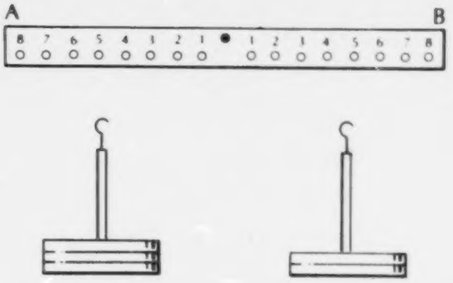
Find *three* other ways to make it balance with 400 on side A and 200 on side B.

You need a system for recording your results. Design a simple table into which you can put your results. Remember how many variables you need to record.

►

Your name: ....

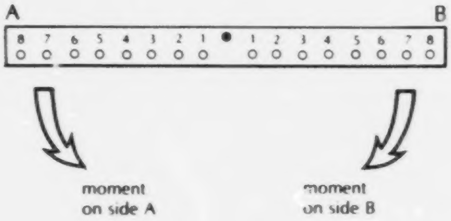
3 ... and more



Start again with 300 g on side A.
and 200 g on side B.

How many different ways can you find to make these weights balance? Write the weights and distances in your table.

4 Just a moment!



The force which tends to pull down one side of the balance is called

the **moment**

on that side of the balance.

The moment on side A can be increased either by:

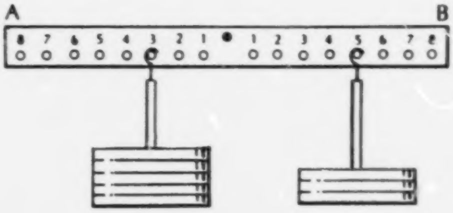
increasing the .... or by increasing the ....

Moment is a **compound variable**. It is made up of two simple variables multiplied together:

The moment on one side of the balance = ... × ....

When the balance is in equilibrium, what can you say about the moment on side A and the moment on side B?

....



This system is in equilibrium.

The moment on the left hand side is

.... × .... = ...

and on the right hand side is

.... × .... = ...

In general, if you have a weight *Wa* on side A, distance *Da* from the centre, and a weight *Wb* on side B, distance *Db* from the centre, what is the relationship between *Wa*, *Da*, *Wb* and *Db* when the balance is in equilibrium?

....

....

Activity 29: Workcard
Equilibrium in the balance

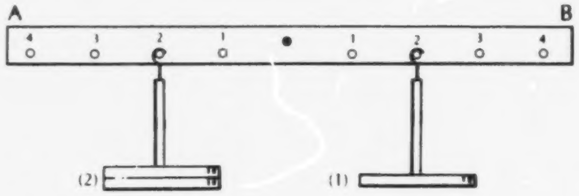
Equilibrium

Problems

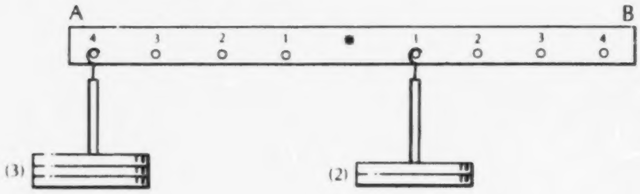
What will happen if the weights are put on to a balance as shown in the diagrams?

1 For each one say whether side A goes down, side B goes down or it stays in equilibrium. Also write what is the moment pulling down side A, and what is the moment pulling down side B.

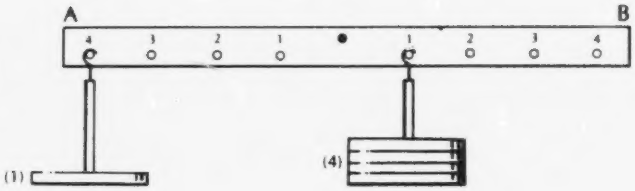
1


A
B
4
3
2
1
1
2
3
4
(2)
(1)

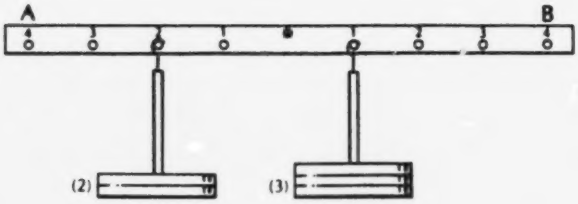
2


A
B
4
3
2
1
1
2
3
4
(3)
(2)

3

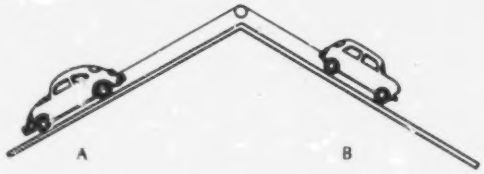

A
B
4
3
2
1
1
2
3
4
(1)
(4)

4


A
B
4
3
2
1
1
2
3
4
(2)
(3)

▶

Here is another system in equilibrium:



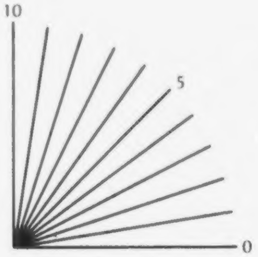
Lots of different arrangements were made by changing the variables of mass and steepness on side A and mass and steepness on side B.

Steepness is difficult to measure so we have invented a 'steepness scale.'

If the slope is 0 it is flat: __________ 0 10

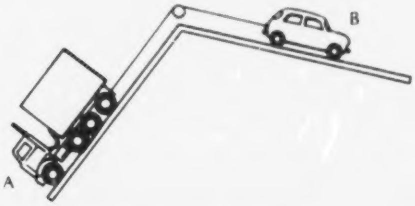
If the slope is 'straight up' it has a steepness of 10:

Copy the diagram and fill in the steepness scale numbers on the slopes (5 has been done for you).

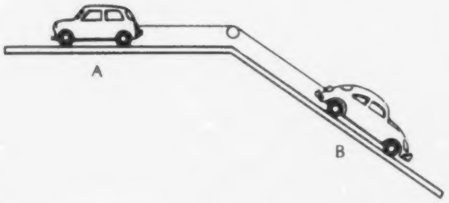


In which direction do you think the cars will move in each of these cases: Will car A go down, car B go down, or neither move?

5



6



Some of the different combinations of steepness and car mass that were used are shown in this table. All of them are in equilibrium.

Side A			Side B		
steepness	mass		steepness	mass	
6	20 g		3	40 g	
2	100 g		4	50 g	
3	30 g		9	10 g	
4	30 g		2	60 g	

▶

Look for a pattern and make a rule which relates the steepness of the hills, the masses of the cars and equilibrium.

....

....

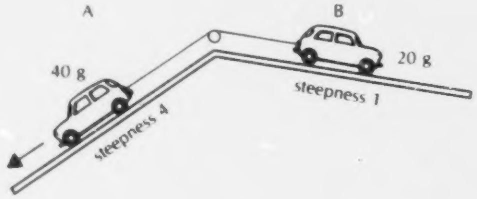
....

Use this rule to say if these systems are in equilibrium. If they are not, say which way car A moves.

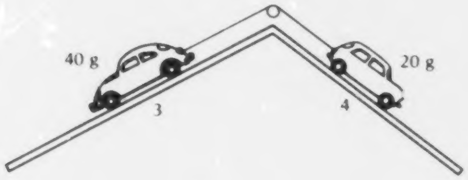
The first problem is done for you.

Example: In equilibrium? ~~yes~~/no

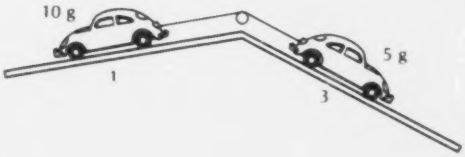
40 × 4 = 160
20 × 1 = 20


A
B
40 g
20 g
steepness 4
steepness 1

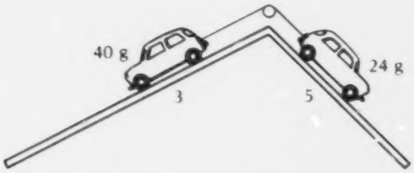
7 In equilibrium? yes/no



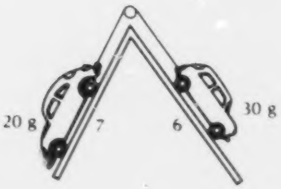
8 In equilibrium? yes/no



9 In equilibrium? yes/no



10 In equilibrium? yes/no



Activity 30: Divers

Compound variables

Introduction

The idea of density is specifically introduced. There is the potential of bringing together compound variables and equilibrium – but even at the level of a puzzling problem, it provides experience of the practical effect of changing the density of a liquid.

Apparatus summary

Per group

- 500 cm^3, 250 cm^3, 100 cm^3 beakers
- Small stoppered tube, dropper, access to salt and a balance

For demonstration

- 500 cm^3 beaker full of paraffin

Per pupil

- Worksheet

Procedure summary

1 Recall the jam jar activity: to predict whether something floats, you have to know both the mass and the volume.

2 Demonstrate that the small stoppered tube sinks when full of water, floats when empty. The problem is to make a 'swimmer' that neither floats nor sinks, and then find its mass.

3 Then add *just* enough water to make the tube sink, then add salt to the water bath. The 'sinker' then floats. Pupils speculate on the explanation and the word density is introduced.

4 They find the volume of the tube by displacement and are taken through the calculation to find the tube's density. Stop here to discuss the idea of density as 'mass for volume'.

5 Pupils devise a way of finding the density of liquids and use it with water and salt solution. It becomes clear that salt solution is more dense than the water and the 'swimmer' is about the same density as water, less dense than salt solution.

6 If time allows, they try a 'floater' in paraffin. It sinks. Conclusions are drawn about the density of paraffin. Some may produce a 'general rule'.

Procedure details

1 Remind pupils of the activity with jam jars, when it was established that to predict whether something floats or sinks, you have to know something about both the mass and the volume. In this activity they will find out more about this compound variable, and also the effect of using different liquids.

2 With a 500 cm^3 beaker full of water, demonstrate that the small test tube, with its stopper, sinks when it is full of water and floats when it is empty.

The students' problem is to add just enough water to it so that it 'swims', neither floating nor sinking, and then find the mass of their 'swimmer'.

3 In part 3 they add *just* enough water to make the tube sink, then add salt to the water bath. This has the effect of making the 'sinker' float. The formal explanation for this is that the liquid is now more dense than the test tube. Pupils may be encouraged to speculate, and the word density may be introduced to describe the difference between the salt solution and the water.

4 The next two parts formalise the notion of density. First they find the volume of the tube by displacement (this itself may cause slower pupils some problems); then they are taken through the calculation to find the tube's density.

This is the heart of the activity. You should stop at this point to discuss the idea of density as 'mass for volume' ('it's heavy for its size'). This is an idea that many were reaching for and some attaining in the jam jar exercise.

5 Proceeding from that idea (perhaps rather cloudy), pupils devise a way of finding the density of liquids (e.g. weigh 100 cm^3 and divide by 100), and use it with water and salt solution. The exact numbers are not critical, but it should be clear that the salt solution is more dense than the water and the 'swimmer' is about the same density as water, less dense than salt solution.

6 If time allows, let them make a 'floater', then try it in a beaker of paraffin that you have at the front. It sinks. This is used as an opportunity to make predictions about the density of paraffin (it is less than that of water).

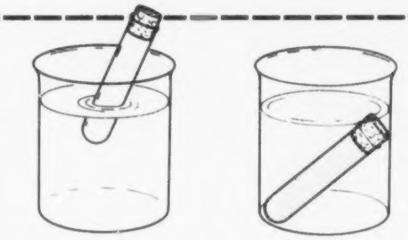
The 'general rule' which some may work towards would be something like 'If a solid is less dense than a liquid, it floats; if more dense, it sinks'.

Your name: ....

Activity 30: Worksheet Divers

Compound variables

1 A swimmer



When the test tube is empty, it floats.

When it is full of water it sinks.

Try to make it 'swim', neither floating nor sinking. So it is just in **equilibrium**.

- Use a dropper to remove small amounts of water until the tube just floats. (Put the stopper in each time you try it.)
- Add water drop by drop until it just starts to sink.

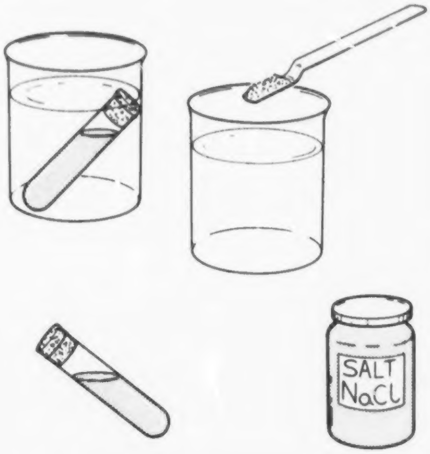
2 Weight?

Take your 'swimmer' out of the water.

Dry it, and weigh it.

weight of 'swimmer': .... g

3 Saltwater



Add one or two more drops of water to the tube so that it just sinks. Now it's a 'sinker'. Take it out of the water.

Add about 4 teaspoons full of salt to the water in the beaker. Stir until it dissolves.

Put the 'sinker' in the salt water. What happens?

....

Can you explain this?

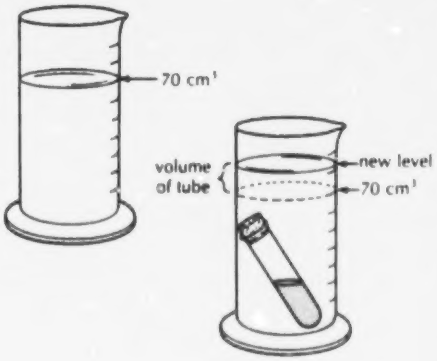
▶

Your name: ....

4 Volume

Now find the volume (the space taken up by) the tube.

- Put the water into a 100 cm^3 measuring cylinder until it is exactly at the 70 cm^3 mark (A).
- Lower the tube into the measuring cylinder.
- Write the new water level in the table (B).
- Calculate the volume of the tube (C).



Volume of water before tube put in: A . 70 . cm^3
Volume of water after tube put in: B .... cm^3
Volume of tube (B − A): C .... cm^3

5 Density

Density is a **compound variable**: weight divided by volume.

The density of something is the weight of 1 cm^3 of it.

Calculate the density of the 'swimmer'. Divide its weight by its volume.

Volume of the tube (from 4 above): C ....cm^3
Weight of 'swimmer' (from 2 above): D ....g
Density of 'swimmer' $\left(\frac{D}{C}\right)$ E ....g/cm^3

6 Density of liquid

Try to think of a way of finding the density (the weight of 1 cm^3) of a liquid, such as water. Use the measuring cylinder and a balance. Discuss your method with your group and with your teacher.

When you have agreed what you are going to do, find the density of (a) water, and (b) the salt solution.

Results:

Your name: ....

Compare

(i) the density of the 'swimmer' with the density of water.
(ii) the density of salt solution with the density of water.

Now, try to explain what happens when you put the 'sinking' tube in salt solution.

....

....

....

....

Extra! Extra!

Start again with a 'swimmer'. Use a dropper to take water out until it just floats in water. Now you have a 'floater'.

Will the density of the tube be more or less than 1 g/cm^3 now?

....

Take the floater out of the water. Dry it. Put it in a beaker of paraffin. What happens?

....

Find the density of paraffin.

Result:

What can you say about the density of the tube if it floats in water?

....

What can you say about the density of the tube if it sinks in paraffin?

....

Try to write a general rule which describes whether a solid object will float or sink in a liquid:

....

....

....

....

Appendix

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2 Two variables .... *Variables* 1
3 The 'fair' test .... *Variables* 2
4 What sort of relationship? .... *Variables* 2
5 Roller ball .... *Variables* 2
6 Gears and ratios .... *Proportionality* 3
7 Scaling: pictures and microscopes .... *Proportionality* 3
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9 Trunks and twigs .... *Proportionality* 4
10 The balance beam .... *Compensation* 5
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17 The behaviour of woodlice .... *Correlation* 8
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Introduction

The Student Manual includes worksheets, workcards, and some example cards. Each student needs a manual to participate in the activities.

Worksheets (w/s) are for students to record their results. Workcards (w/c) give information, instructions, or problems. Example Cards (e/c) provide illustrations of concepts for discussion.

A few of the activities require simple apparatus to be made which is not standard laboratory equipment. These are Activities 5, 8, 9, 10 (also used for 29), 26, 27, and 28. Activities 2 (experiment C) and 16 require some advance preparation.

Activity 1: What varies?

Variables

For demonstration

- About 15 different text books, varying in colour, size, etc.
- Squares and triangles cut from coloured card. One each as follows:

TRIANGLES	SQUARES
small blue	small red
medium blue	medium red
large blue	large red
medium red	large blue

- Two 500 cm^3 beakers lined with blue paper, numbered 1, 2.
  Two 250 cm^3 beakers lined with red paper, numbered 3, 4.

  1 (500 cm^3) is empty.
  2 (500 cm^3) has a 100 g weight in it.
  3 (250 cm^3) contains sand to make it the same weight as beaker 1 (the empty 500 cm^3).
  4 (250 cm^3) contains sand to make it the same weight as beaker 2 (the 'heavy' 500 cm^3).

Contents of the beakers should not be visible to pupils.

- A top pan balance (ideally weighing to nearest gram or even 5 g).

Per pupil

Worksheet
Workcards – One set of cards between two pupils is adequate unless they are to be taken home for homework.

Activity 2: Two variables

Variables

Note Advance preparation needed for Experiment 3.

Per pupil

Worksheet

Eight 'stations' are set around the lab – two sets for each of four experiments.

Experiment 1
Spring balance
100 g weight hanger
Three 100 g weights
Pulley and string
Method of fixing string to base (see Workcard)
Workcard A

Experiment 2
One 100 cm^3 beaker
Abour four other glass or plastic containers, all circular cross section, all at least 100 cm^3 volume, of varying heights and diameters, numbered 1 to 4.
Water
Half-metre rule
Workcard B

Experiment 3
Four sycamore, elder, or other large leaves which do not have a waxy coating, hung on a line. These must be prepared at least two days in advance. They are numbered 1 to 4, and then:

1 has Vaseline spread on its top surface.
2 has Vaseline spread on its bottom surface.
3 has Vaseline spread on both surfaces.
4 has no Vaseline.

Workcard C

Experiment 4
Workcard D

Activity 3: The 'fair' test

Variables

For whole class

- Fifty or 60 lengths of tubing:

  some plastic, some glass,

  some 'long', some 'medium' and some 'short' (e.g. about 10 cm, 20 cm, 15 cm),

  some 'wide', some 'medium' and some 'narrow' (e.g. about 1.25 cm, 1.0 cm, 0.75 cm).

The actual dimensions are not important; the point is to have different sizes that can clearly be categorised into three groups as 'long', 'medium', 'short' etc.

- Weak disinfectant solution in three or four beakers around the lab.

Per pupil

Worksheet
Workcard A – problems, high notes, low notes
B – problems, some 'fair' tests?

Activity 4: What sort of relationship?

Variables

Note There are two main experiments. Both are written here as pupil experiments, but one will probably be done as a demonstration.

Per group

Experiment 1
Retort stand with clamp
Spring
Weight hanger and 100 g weights
Metre or half-metre rule
Workcard A

Per group

Experiment 2
Funnel, about 75 cm diameter, plus holder
Two 250 cm^3 beakers, one containing 100 cm^3 lubricating oil, such as Castrol 10/30
Tripod, gauze and Bunsen
Stirring thermometer
Stop clock
Workcard B

Per pupil

Worksheet

General

Soap or detergent for washing oily hands, beakers, etc.
Paper towel for spillages

Safety point Check that you know the location and usage of the asbestos blanket and/or carbon dioxide fire extinguisher suitable for oil fires.

Activity 5: Roller ball

Variables

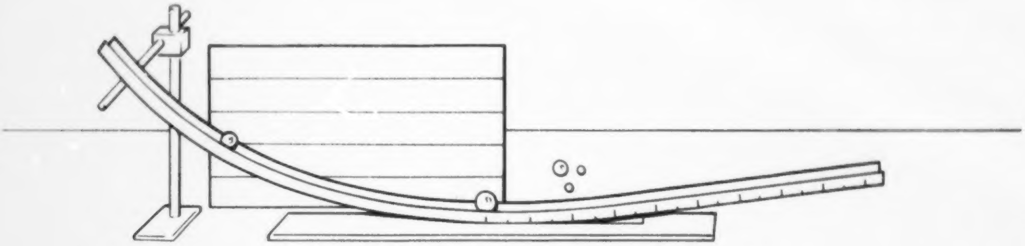
For demonstration

- Track on which balls can roll (e.g. curtain track). The track should have one steep side from which a ball (the 'roller' ball) can be released, to roll down and hit a 'target' ball resting at the bottom. The target ball is pushed up the other side.

  The roller ball side is quite steep and may be curved or straight. The target ball side should be straight, and slope upwards only slightly. Scales are needed to show the height from which the roller ball is released, and the distance that the target ball travels. We used a board behind the roller ball end, and a scale marked on the target ball track.
- Variety of balls e.g. steel, plastic, brass, lead; different sizes etc. Include three coloured marbles, same in every respect except colour.
- Top pan balance

Per pupil

Worksheet
Workcard plus graph paper


balls rolled from this side

The 'target' side of the track should be as straight as possible, so that distance along is proportional to height.

Activity 6: Gears and ratios

Proportionality

Per group

- Depending on what you have available, *either* pairs of different sized gears which can mesh and turn, *or* a pair of different sized pulleys joined by a string or chain.

  The small one should turn a complete number of times (no fractions) for each one or two turns of the large one. There should be two or three different ratios available, so that after doing one, groups can swop and try another.

  Technical Lego and Fischer Technic gears are appropriate, but it is possible to make your own gears by wrapping corrugated paper around different sized tin cans.
- Copy of map, preferably of the district around the school. The geography department may be able to lend you some. Alternatively, you could make a scale sketch of the school buildings and grounds.
- Pile of about ten 'pennies' (could be real pennies or other small pieces of metal of even thickness).
- Pile or pad of paper, at least 30 sheets thick.
- Ruler marked in cm and mm.

For demonstration

- A scale model car, or train, etc.
- (Optional) A 'Barbie' doll, Action Man, or other doll.

Per pupil

Worksheet
Workcard

Activity 7: Scaling: pictures and microscopes

Proportionality

Per group

Microscope
Forceps
Glass slides and coverslips
Transparent ruler or graph paper sellotaped to slide to provide means of measuring diameter of field of view.

Per class

(Optional. Maybe only the more able groups will get as far as the onion skin exercise.)
One onion
Filter paper
Iodine
Teat pipette (dropper)

Per pupil

Worksheet
Workcard A
Workcard B – problems

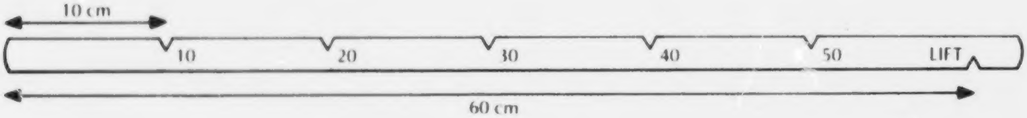
Activity 8: The wheelbarrow

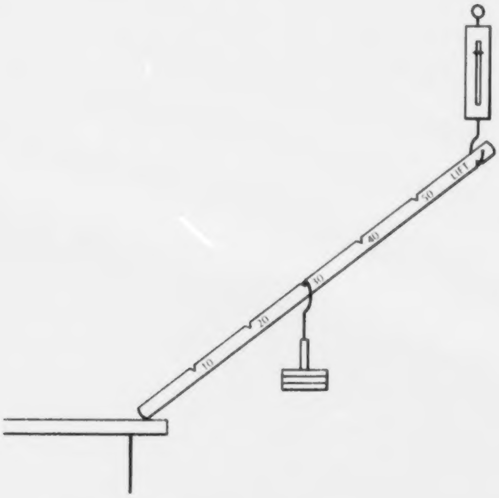
Proportionality

Per group

- Length of dowel, about 65 cm long and about 6 mm in diameter. This is to represent a wheelbarrow. It should be grooved and marked as shown.

The grooves are to allow weight hangers to be located accurately at the marks. Note the groove on the underside near the top, for locating the spring balance.





- 10 N Spring balance
- Weight hanger
- Ten 100 g slotted masses
- 50 g slotted mass

Per pupil

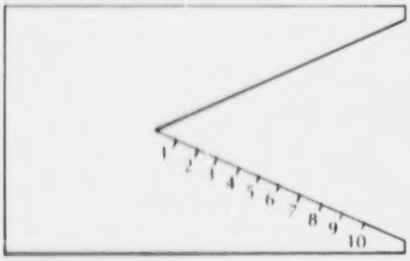
Worksheet
Graph paper may be needed also
Workcard

Activity 9: Trunks and twigs

Proportionality

Per group

- *Either* a half-metre rule and a caliper gauge suitable for measuring the thickness of small tree branches;
- *Or* a 'diameter measurer' made from thick card or thin plywood like this:



A full size master of this is included in the Example Card material.

- **Workcard, if possible protected with plastic. Two versions are provided, according to whether you use calipers or the diameter measurer.**

Per pupil

Worksheet and something to press on.

It is a good idea to identify in advance bushes near the school which are suitable for this exercise.

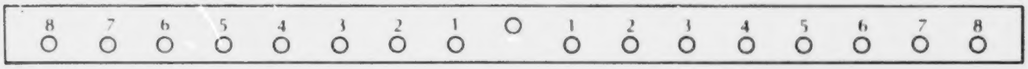
If it proves impossible to take the pupils out to measure bushes, branches cut from trees which have plenty of joints could be brought in. **As a last resort, pupils could work from Example Card drawings.**

Activity 10: The balance beam

Compensation

Per group

- A piece of wooden lath 1 metre long and 1.5–2 cm wide by about 70 mm thick, drilled in the centre and every 6 cm out to give eight holes on either side. If you don't mind drilling metre rules, they would do. If you want to be very subtle the outer holes can be drilled fractionally closer than a regular 6 cm in order to allow for the weight of the beam:



Given the natural unevenness of the density of wood, each beam will probably have to be individually balanced with a drawing pin or Blu-tack after it is made.

Note This same apparatus will be used again in Activity 29.

- Retort stand and clamp, with a nail for beam to swing on
- Two hangers
- Ten 100 g weights

If the weight hanger hooks do not pass through the holes in your beam, you will need a pair of S hooks as well.

Activity 11: Current, length and thickness

Compensation

A note on ammeters

The current range in this experiment is from about 0.4 A to 1.5 A. Thus an ammeter with a 2 A full scale reading would be ideal – even better if it had only one scale that could be read directly with no conversion factor. It is far more likely that your ammeters will be double scale and will read '10' or so on full scale, so that even after you have fitted an appropriate shunt some pupils will have difficulty reading the scales correctly. It may help to tape over unwanted plugs on the meter, and if possible to mask unwanted scales.

A note on resistance wire

The activity has been developed using 28, 30, and 36 swg constantan wire. If the resistance wire you have available is of very different thicknesses, or different materials, the experiments will have to be checked.

For demonstration

- Power pack set to 12 V or 15 V DC
- 12 V car bulb in holder
- Connecting wires
- Ammeter
- **1.6 m length of constantan wire (copper-nickel alloy), 30 swg .**

Per group

- Power pack set to 4 V (Dry cells will not work for this activity. If you do not have power packs or a low voltage DC supply, you could try using accumulators.)
- Ammeter (see note above)
- Connecting wires (push connectors and crocodile clips, to make the circuit shown on the Worksheet).
- 1.6 m lengths of constantan wire, 30 swg and 36 swg (only the first is given out initially). A few 1.6 m pieces of 28 swg in reserve for more able groups who finish quickly.

Per pupil

Worksheet
Workcard

Activity 12: Volts, amps and watts

Compensation

Per group

Two alternative versions of the pupil activity are offered, according to what equipment you have. Some schools have set up both, as a circus.

Either Torch bulbs:

- Battery pack with three good 1.5 V cells.
- Ammeter reading 1 A full scale
- Mes (torch) bulb holder
- Connecting wires
- Three different types of bulb. Common ones available are rated as '1.25 V', '2.5 V', and '3.5 V' or '4.5 V', but you can use any similar ratings which give light (and don't blow) with one, two, and three cells respectively. It is an idea to mark either the boxes they come from or, better, the bulbs themselves, with little dots of paint – green for the 4.5 V, orange for the 3.0 V, and red for the 1.5 V. This emphasises that the last are most fragile and have to be treated with care.

Or Car bulbs:

- Power pack to give 6 and 12 volts DC
- Car bulb (small bayonet) holder
- Ammeter reading 5 A full scale
- Connecting wires
- Selection of car bulbs, such as 6 V/5 W, 6 V/24 W, 6 V/36 W, 12 V/5 W, 12 V/24 W, 12 V/36 W

Per pupil

Workcard A for *either* torch bulbs *or* car bulbs
Workcard B – problems

Activity 13: Spinning coins

Probability

Per pupil (or group)

One coin
One calculator

Worksheet
Example Card

Activity 14: Combinations

Combinations

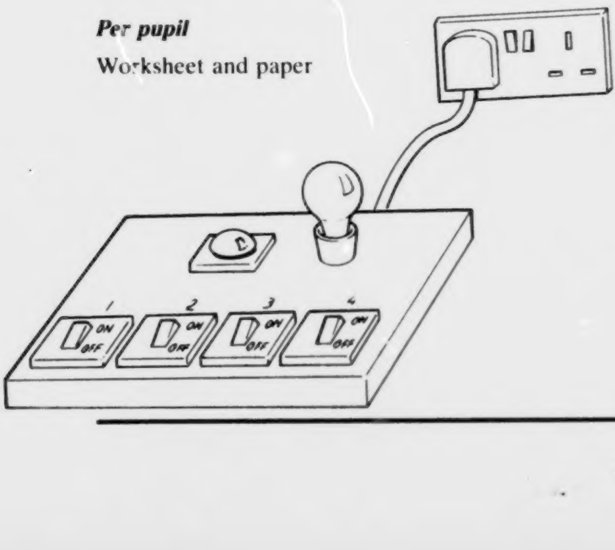
Per group

Two dishes (Petri dishes are ideal)
Cotton wool
Cress seeds
Two sticky labels
Tinfoil/black paper to exclude light
Sellotape

One group will also need:
Two boiling tubes with bungs
Alkaline pyrogallol

Per pupil

Worksheet and paper

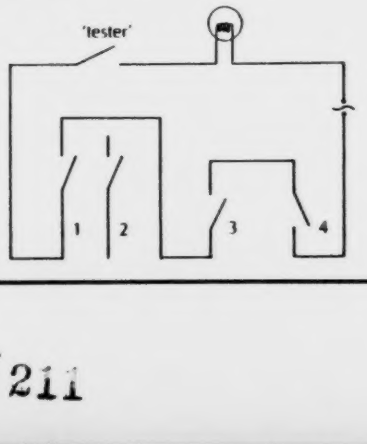


For demonstration

- A board on which is a mains lamp holder and bulb; four switches clearly numbered 1, 2, 3, 4; and a 'tester button'. Power is supplied through a mains lead fitted with a three pin plug (3 A fuse adequate). The board must be built into a box and be electrically safe.

The lamp holder is wired in series with the tester button and switches 1, 3, and 4. Switch 4 is fitted upside-down, with the label ON corresponding to the real OFF. Switch 2 is not wired in at all.

The effect is that the bulb lights when the 'tester button' is pushed only when switches 1 and 3 are 'ON' and switch 4 is 'OFF'. Switch 2 has no effect.



Activity 15: Tea tasting

Probability

For demonstration

Five tea cups
A pot of tea
Some milk
Example Card

Per group

Five identical coins
Workcard A

Per pupil

Worksheet
Workcard B – problems

Activity 16: Interaction

Variables

> *Note* Experiment 2 has to be set up at least one week in advance.

Per group

Experiment 1
Test tube rack with four test tubes labelled A, B, C, D. Each test tube contains about 10 cm^3 of a suspension of dried yeast in water and a drop of lemon juice (or vinegar).
A spatula
A little sugar on a watch glass or filter paper
Ruler with mm marking
Access to a water bath at about 35°C.
If this is not available, each group will need a beaker, Bunsen, tripod, and gauze.

For demonstration

Experiment 2
Large beaker half full of water, Bunsen, gauze and tripod.
The rest must be set up in advance – preferably a week or more.
Three test tubes labelled 1, 2, 3, each containing an iron nail.

1 is sealed and contains some calcium oxide or silica gel drying agent as well as the nail.
2 is sealed also. It is full to the cork with water that has been boiled for ten minutes to expel any air, then poured over the nail into the tube and quickly sealed.
3 is open to the atmosphere and has water in it about half way up the nail.

Per pupil

Worksheet

Activity 17: The behaviour of woodlice

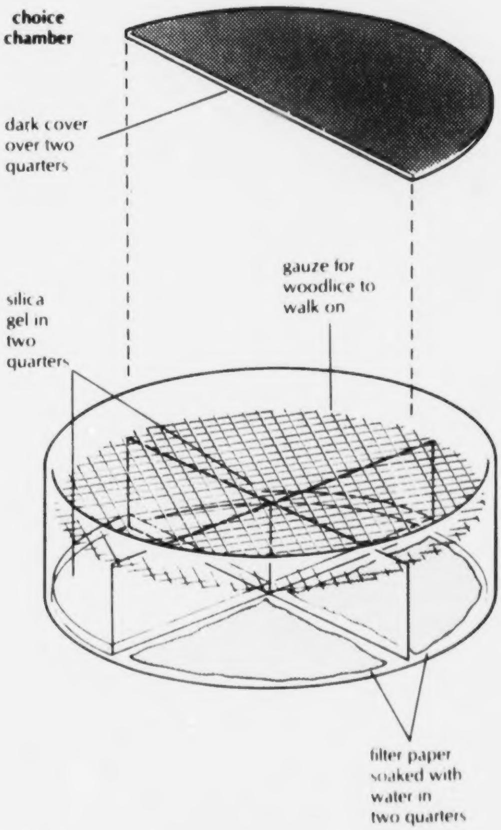
Correlation

Per group

One choice chamber
Gauze for woodlice to walk on
Dry silica gel crystals
Black paper shields to fit over half of choice chamber
Twenty woodlice
Optional – One lamp

Per pupil

Worksheet


choice chamber
dark cover over two quarters
gauze for woodlice to walk on
silica gel in two quarters
filter paper soaked with water in two quarters

Activity 18: Treatments and effects

Correlation

Per group

- One pack of 20 treatment/effect cards. Material for five packs of cards is provided so that different groups have different 'experiments':

  cows and green pills
  sheep and red pills
  pigs and brown pills
  wheat and fertiliser
  roses and leafshine

For each pack there are two master sheets to be photocopied and cut up to make 20 cards. If each pack is on different coloured paper it helps to identify them.

Per pupil

Worksheet

For the teacher

Example Cards A and B

Activity 19: Sampling

Probability

Per group

About 500 melon seeds
Plastic bag large enough to hold the seeds easily
Pen to mark melon seeds
Workcard – data sheet on holiday resorts

Per pupil

Worksheet

Activity 20: Throwing dice

Probability

Per group

- A pair of dice, different colours. The Worksheet refers to red and green dice, so use those colours if you can.

Per pupil

Worksheet

For the teacher

Example Card

Activity 21: Making groups

Probability

Per group

- Eight test tubes in rack, labelled A–H, containing very small quantities (less than enough to fill the rounded bottom of the test tube) of:

  calcium carbonate, $CaCO_3$
  calcium sulphate, $CaSO_4$
  carbon powder
  copper sulphate, hydrated, $CuSO_4.5H_2O$
  iron II sulphate, $FeSO_4$
  potassium nitrate, KNO_3
  sodium chloride, NaCl
  sulphur powder

There is nothing magical about these particular substances, once you have a selection which includes some white and soluble in water, some white and insoluble, some coloured and soluble, and some coloured and insoluble.

- Workcard A –Creepy crawlies
- Workcard B – Big animals

  These could be reduced together to one A4 sheet, but then pupils will have to be told that the scales on the creepy crawly pictures are wrong.

One or two sets only

- Selection of about 15 tins, packets, jars, etc. from a larder, with as much variety as possible. Examples might include baked beans, tinned fish, meat, cake mix, jam, dog food, herbs, flour, vegetables, orange squash, etc.

Per pupil

Worksheet

Activity 22: More classifying: birds

Classification

Per group

- Workcard A – pictures of various animals
- Workcard B – set of 20 bird pictures. These are provided as five A4 masters which can be photocopied, then sliced into individual cards and arranged in sets. Keep the humming bird separate. It is to be given out after the others.

Per pupil

Worksheet

Activity 23: Explaining states of matter

Formal models

Per pupil

Safety glasses
Worksheet

Per group

- Bunsen burner
- Test tube holder
- Test tube rack
- Tripod and pipeclay triangle
- Tongs
- Asbestos mat
- Samples of the following, in test tubes or crucibles, ready to be given out:
    - ice, in small blocks that can be put in test tubes to give out;
    - sulphur powder, one spatula full in each test tube;
    - a small lump or some granules of lead or plumber's solder, in a crucible;
    - paraffin wax, lower melting point if you have a choice, filling the rounded bottom of a test tube.

For demonstration

- Stearic acid, enough to fill a boiling tube to about 2 cm depth;
- A few iodine crystals in a boiling tube.

Activity 24: Explaining solutions

Formal models

Per pupil

Worksheet

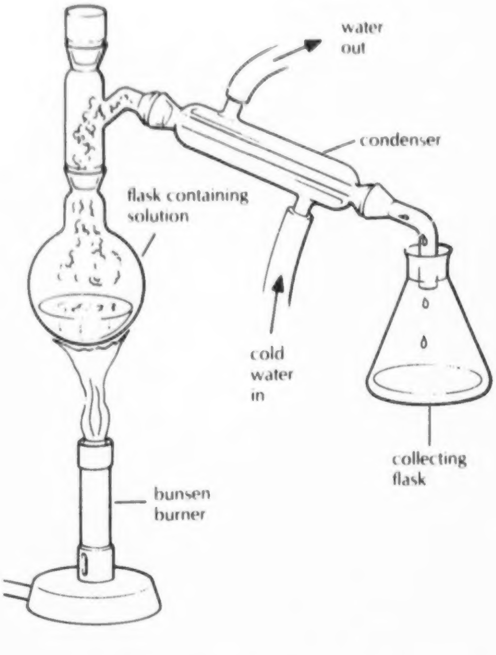
Per group

- Test tube rack
- Corks to fit test tubes
- Bunsen burner
- 250 cm^3 beaker
- Tripod and gauze
- Watchglass to fit over beaker
- Samples of the following ready to give out to each group (enough to cover the flat end of a small spatula in a test tube):

    common salt, sodium chloride, $NaCl$;
    sulphur powder;
    copper sulphate (hydrated), $CuSO_4.5H_2O$.

For demonstration

- Naphthalene
- A boiling tube
- Propanone (acetone)
- Clear blue copper sulphate solution in a complete simple distillation apparatus:



Activity 25: Explaining chemical reactions

Formal models

Per pupil

Worksheet

Per group

- A small candle – either a cake candle, or a piece of a big candle
- Test tube rack
- Bunsen burner
- Heat resistant mat
- One boiling tube
- Two test tubes
- Samples of the following, ready to give out to each group:
  - sulphur powder, to fill the rounded bottom of a test tube;
  - copper metal (turnings), a spatula full;
  - zinc metal (granulated), three or four pieces;
  - dilute sulphuric acid, about 2 cm depth in a boiling tube.

For demonstration

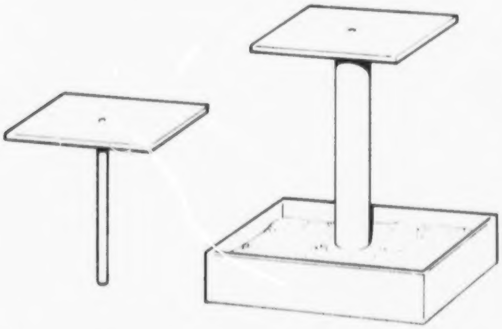
Flame resistant ('asbestos') mat
Sulphur powder
Iron filings
Spatula

Activity 26: Pressure

Compound variables

Per group

- 'Pressure toadstools'. These are pieces of rod about 10 cm in length, each with a square of hardboard about 5 × 5 cm attached to the top.
  Square or rectangular section rod is best, but you can use dowel rod. The important thing is that the rods have a variety of different diameters. We used a range of diameters from 5 mm to 2 cm.



You need about five or six rods of each thickness so that each group of pupils can choose a range of thicknesses.

- Small trays or boxes with damp sand to a depth of about 3 cm.
- Slotted weights

For demonstration

A bottle of orange squash (or similar)
Water
A 250 cm^3 measuring cylinder
Some drinking glasses

Per pupil

Workcard – problems
(There is no Worksheet for this activity.)

Activity 27: Floating and sinking

Compound variables

For demonstration

- Sets of jars (see the Worksheet):
  - (a) five the same volume, varying masses, labelled A–E;
  - (b) six the same mass, varying volumes, labelled 1–6.

Jar 6 and jar A is the same jar with two labels.

For the first series you can use 2 lb jam jars, with sand added to them in increasing amounts so that their masses are:

A – 400 g, B – 600 g, C – 800g, D –1000 g, and E – 1200 g.

For the second series, the smallest (1) should be about spice jar size and the largest (6) is the same as jar A. All of these are weighted to 400 g. The smallest ones need lead shot but sand works for the larger ones.

- Two extra jars:

  X is the same size as jar 4, but weighted to 800 g.

  Y is the same size as jar 5, but weighted to 600 g.

It is better if all of the jars are covered, or painted inside so that the contents cannot be seen. Remember that they will be put in water. Covers and labels should be waterproof.

- A simple balance – weighing to the nearest 100 g.
- A clear plastic or glass trough or aquarium, with enough water to sink largest jar.

(This activity could be done as group work, but you would need a lot of jars!)

Per pupil

Worksheet
Workcard B – problems

Per pair

A set of 32 jar 'playing cards' (Workcard A). Cut into 32 individual cards, each with a jar on the front and an S or F on the back. Shuffle the set and hold them together with a paperclip. With luck, you should be able to re-use the cards for a number of classes.

Activity 28: Up hill and down dale

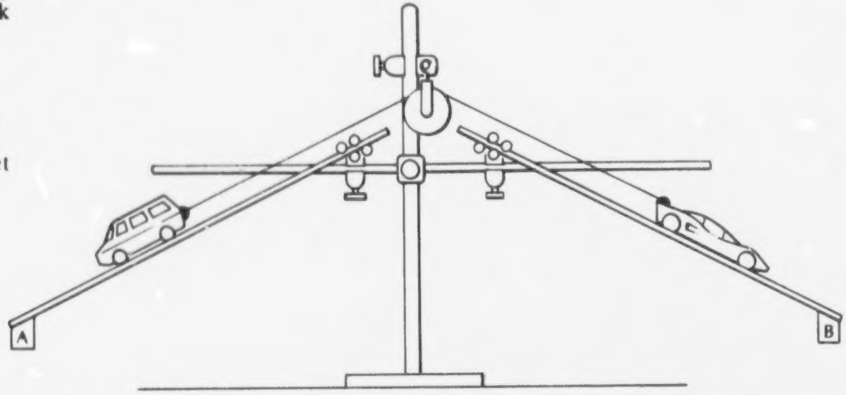
Equilibrium

Per group

One retort stand (rod and base)
Two tracks, labelled A and B
Two bosses and three clamps
One retort stand rod
Two 10 g weights
One pulley
Glue Stick
Two cars
String

Per pupil

Worksheet



The two lengths of 'Hotwheels' track are held in clamps as two sides of a hill. A car rests on each. The cars are attached to each other by a thread passing over a pulley at the summit of the hill, the thread held on the cars with Blu-tack.

'Hotwheels' track itself is too flexible, and each length should be attached (tacks or Blu-tack) to a length of lath. Alternatively, you can buy suitable plastic strip sold as cable conduit in electricians' supply shops. You can just use half-meter rules as roads but, having no sides, the cars tend to fall off.

(We have done this with model railway cars on 30 cm lengths of track tacked to strips of board, but apart from being rather expensive, it does not run as well as cars on 'Hotwheels' track.)

You will need to spend some time before the lesson establishing the best way to arrange the clamps and stands. We made up in advance the cross bar with three bosses and two clamps as a unit.

Per pupil

Worksheet

Activity 29: Equilibrium in the balance

Equilibrium

Per group

The same balance beams used for Activity 10: 1 m long lath with hole in centre and eight holes either side from which weights can be hung. Label the sides A and B.

Two hangers
Six 100 g slotted weights

Per pupil

Worksheet
Plain paper
Workcard – problems

Activity 30: Divers

Compound variables

Per pupil

Worksheet

Per group

One 500 cm^3 beaker
One 250 cm^3 beaker
One 100 cm^3 measuring cylinder
One small (100 × 15 mm) test tube with rubber bung*
A spatula
A stirring rod
A dropper

Access to:
  water
  common salt (technical grade rock salt is OK)
  a balance
  paper or cloth towel

For demonstration

- A 500 cm^3 beaker filled with paraffin (ordinary household paraffin is best).

*We found that these worked well, but many small bottles would do instead. The important things are that: they must sink in water when full of water (many plastic containers do not); they must have water-tight stoppers; they must be short enough to be immersed in a 500 cm^3 beaker (unless you use larger beakers); and narrow enough to go into a 100 cm^3 measuring cylinder (unless you use bigger measuring cylinders).

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